Solar Rooftop Safety

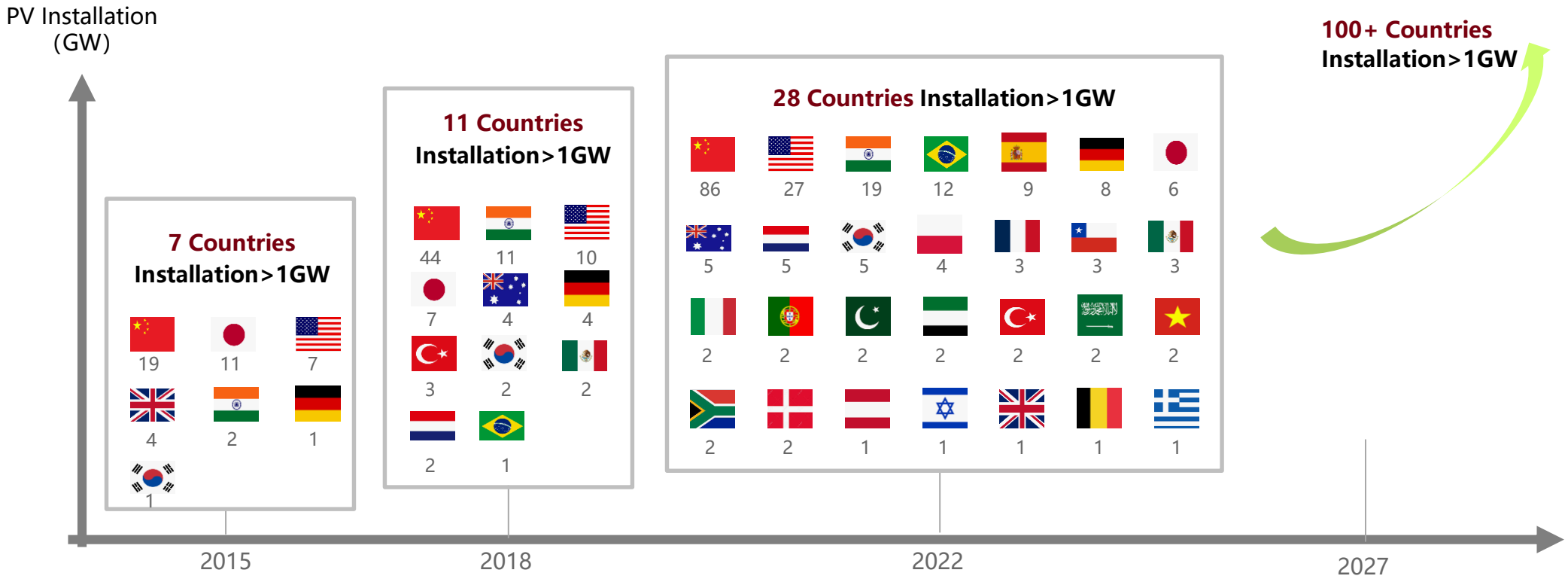
Challenges and Solutions for Solar Rooftop Safety Issues

1

Trends

Driven by "policy + business", PV will be deployed on a global scale

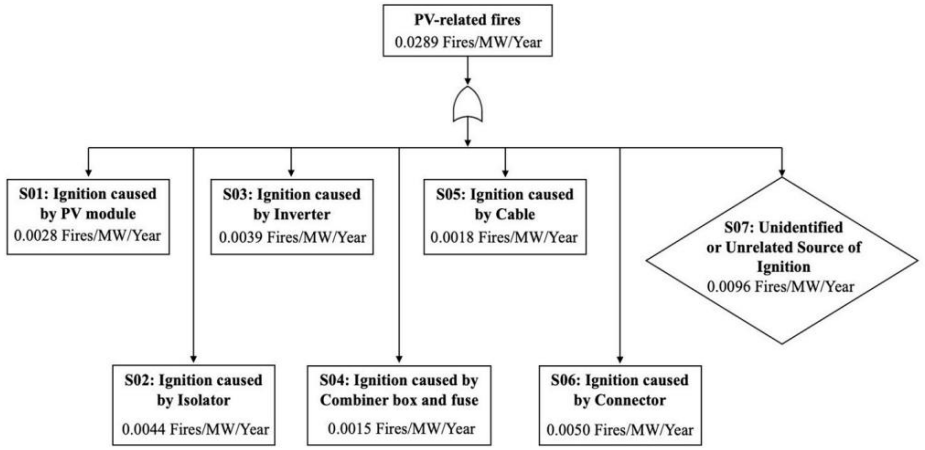
- Carbon neutrality will become global. The number of countries, where the annual installation capacity is greater than 1 GW, will increase from 7 in 2015 to 28 in 2022 and the speed of increase will be accelerated.
- The PV module and cell prices decrease rapidly, the return on investment (ROI) of C&I PV project will decreases by 50% and the IRR increases by more than 10%.



DC Side Problems become the main cause of PV Safety Hazards

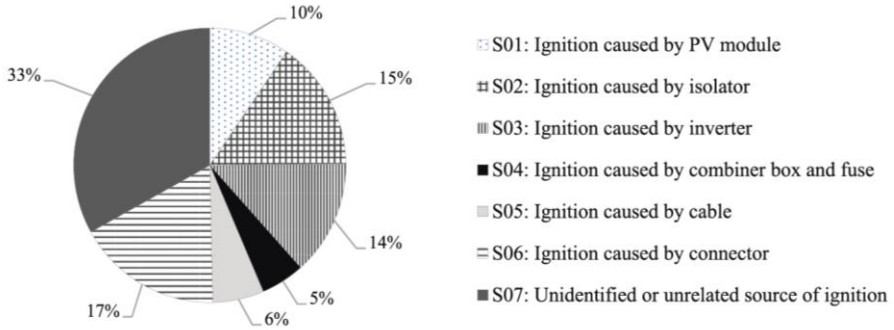
According to the 2022 report, PV Fires

0.03/MW/year



Fault tree events and codes linked with the fault tree diagram presented in Fig. 2.

Code	Event	Code	Event	Code	Events
S01	Ignition caused by PV module	A6	Damages from mountings	D1	Water ingress
S02	Ignition caused by isolator	A7	Excessive snow loads	D2	Loose screw terminals
S03	Ignition caused by inverter	A8	Vandalism	D3	Component damage
S04	Ignition caused by combiner box and fuse	A9	Thermal expansion or contraction	D4	Installation error
S05	Ignition caused by cable	A10	Metallisation distortion	E1	Pulling out of cables
S06	Ignition caused by connector	B1	Moisture ingress	E2	Weathering effects
S07	Unidentified or unrelated source of ignition	B2	Loose screw terminals	E3	Damages from animals
X1	Failure/Absence of fault detection and interrupting devices	B3	Installation errors	E4	Installation errors
X2	Arcing/Overheating	B4	Manufacturing defects	F1	Moisture ingress
X3	Module damage	B5	Damaged component	F2	Loose screw terminals
A1	Corrosion	C1	Moisture ingress	F3	Incorrectly crimped contacts
A2	Bypass diode failure	C2	Cable damage	F4	Physical damage
A3	Installation error	C3	Installation error	F5	Installation error
A4	Manufacturing defect	C4	Lack of ventilation	F6	Incompatible plugs and sockets
A5	Damages from frame distortion	C5	Manufacturing defects	F7	Poorly soldered joints

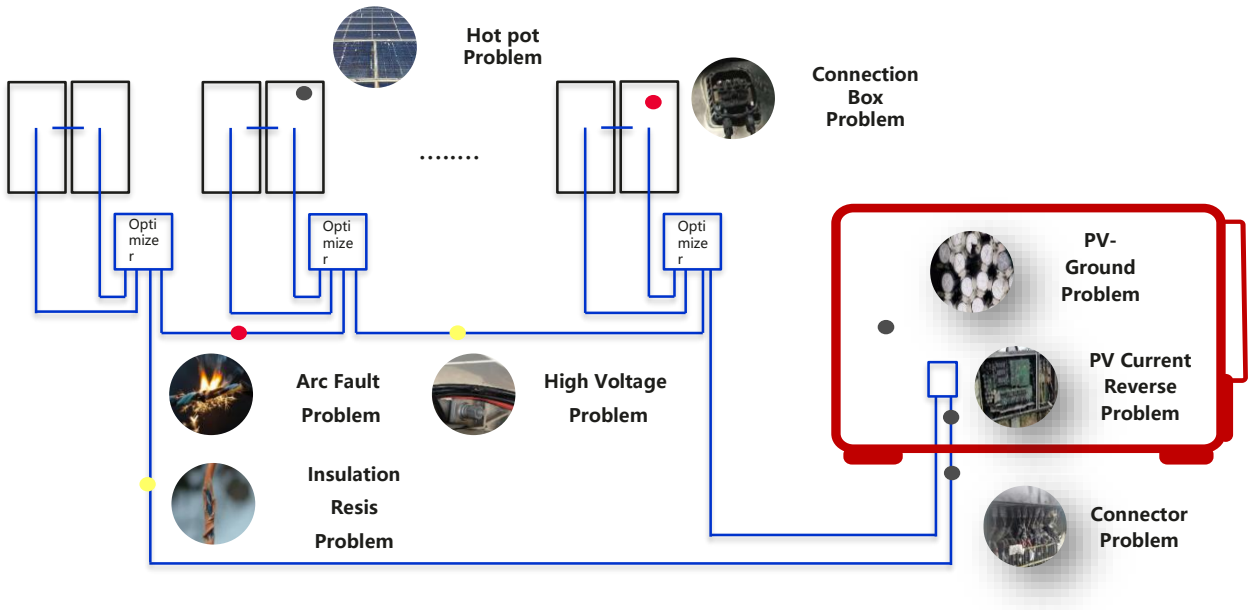


- **Equipment problems** and **installation errors** account for nearly **80% of the fire problems.**
- According to the fire location statistics, the **DC side occupies 75%** of the problem.

DC Side needs to consider more information & Safety standards also needs to be upgraded

The size of the silicon wafer Enters new Period (166/182/210)

Causing the increase of DC Side Energy Density



Reason1

In the traditional PV string solution, there are **few electronic components** on the PV module side. Therefore, DC fault point **detection and signal transmission** cannot be implemented

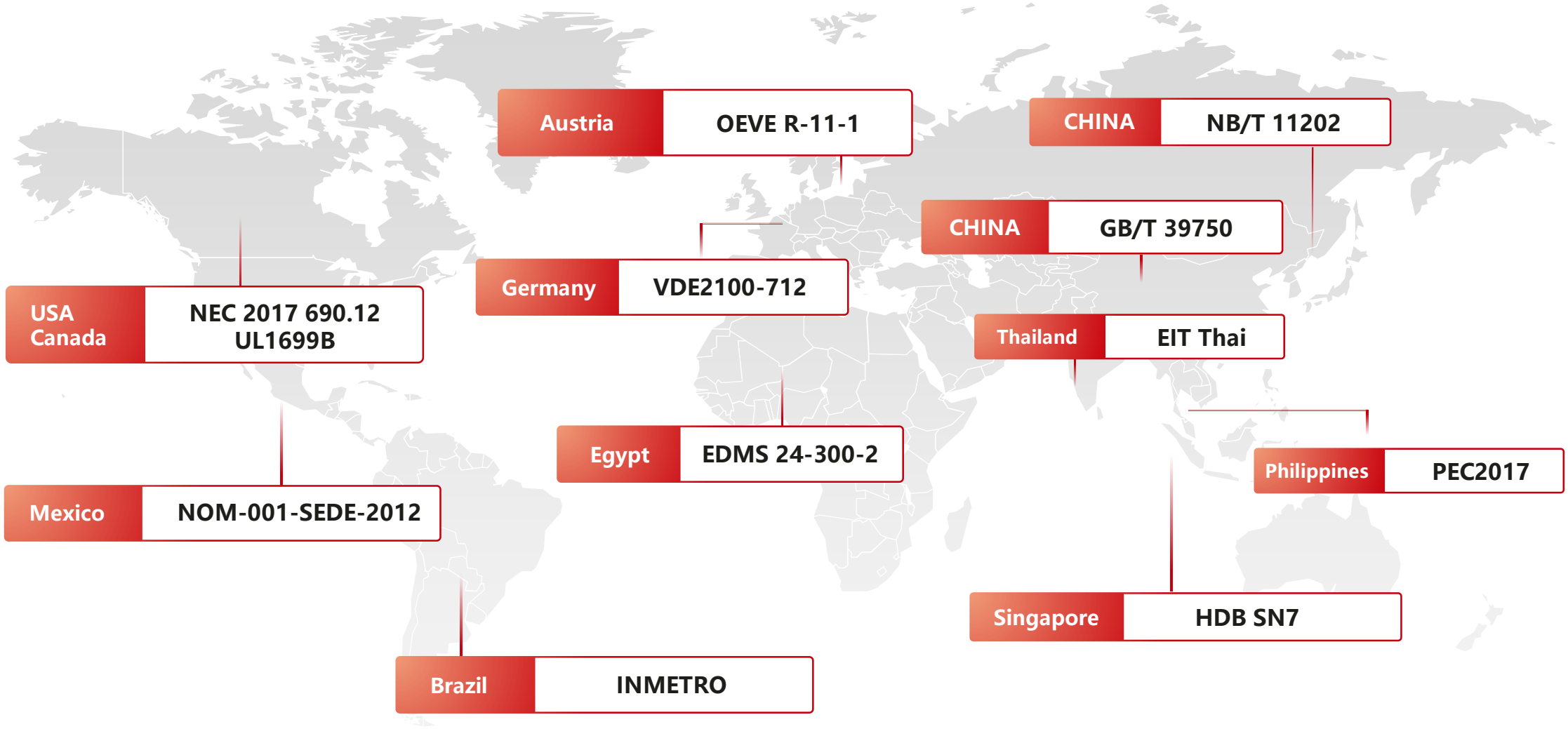
Reason2

The length of the cable between the PV module and the inverter is usually **longer than 50 m,** causing **large interference** of **external EMC signals** As a result, the traditional solution has a **high false positive rate**

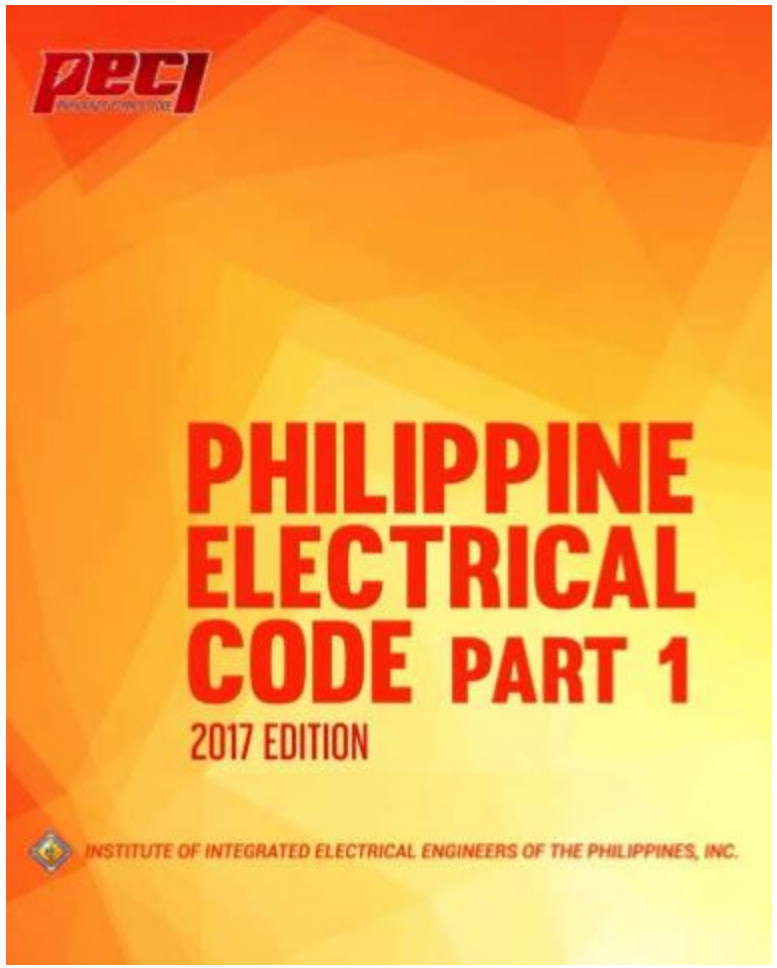
Reason3

The safety standards on the DC side are not fully considered. **New Module, New Networking and New Fault Points**, all of those need to **be upgraded**.

Improving DC Safety Standard has become a global Trend



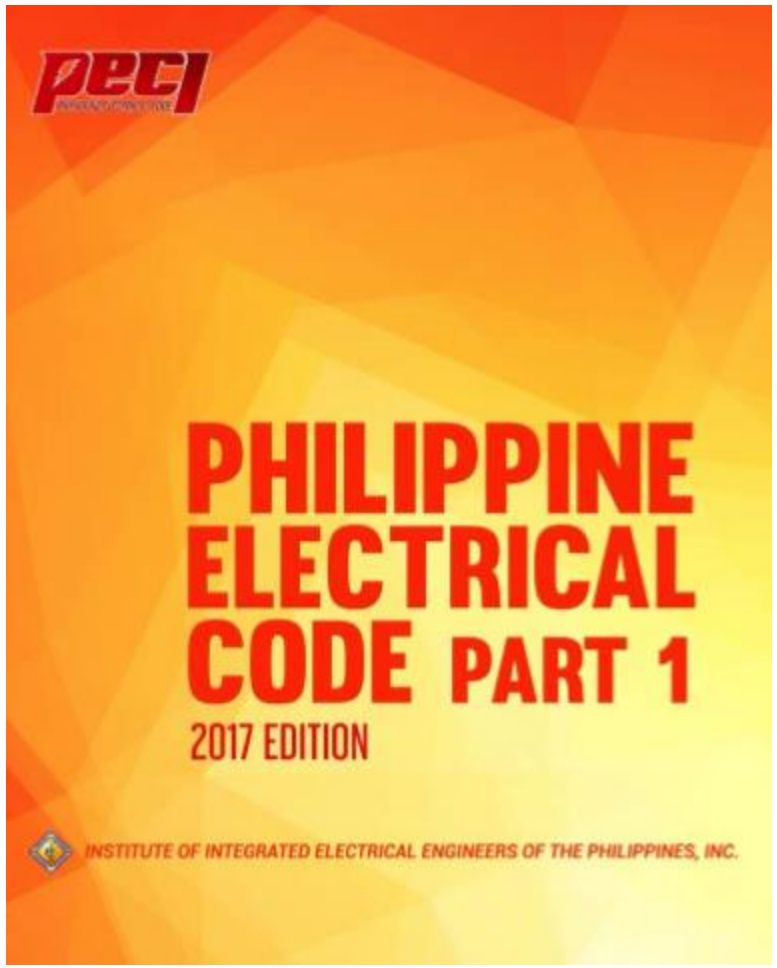
PEC Compliance for Rapid Shutdown


pec
PHILIPPINE ELECTRICAL CODE PART 1
2017 EDITION
INSTITUTE OF INTEGRATED ELECTRICAL ENGINEERS OF THE PHILIPPINES, INC.

6.90.2.6 Rapid Shutdown of PV Systems on Buildings. PV system circuits installed on or in buildings shall include a rapid shutdown function to reduce shock hazard for emergency responders in accordance with 6.90.2.6(A) through (D) as follows.

Exception: Ground mounted PV system circuits that enter buildings, of which the sole purpose is to house PV system equipment, shall not be required to comply with 6.90.2.6.

PEC Compliance for AFCI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6.90.2.5 Arc-Fault Circuit Protection (Direct Current). Photovoltaic systems operating at 80 volts dc or greater between any two conductors shall be protected by a listed PV arc-fault circuit interrupter or other system components listed to provide equivalent protection. The system shall detect and interrupt arcing faults resulting from a failure in the intended continuity of a conductor, connection, module, or other system component in the PV system dc circuits.

Exception: For PV systems not installed on or in buildings, PV output circuits and dc-to-dc converter output circuits that are direct buried, installed in metallic raceways, or installed in enclosed metallic cable trays are permitted without arc-fault circuit protection. Detached structures whose sole purpose is to house PV system equipment shall not be considered buildings according to this exception.

From Whole Plant to devices, Only System-level DC Safety Solutions will help Green Power Go into Everywhere

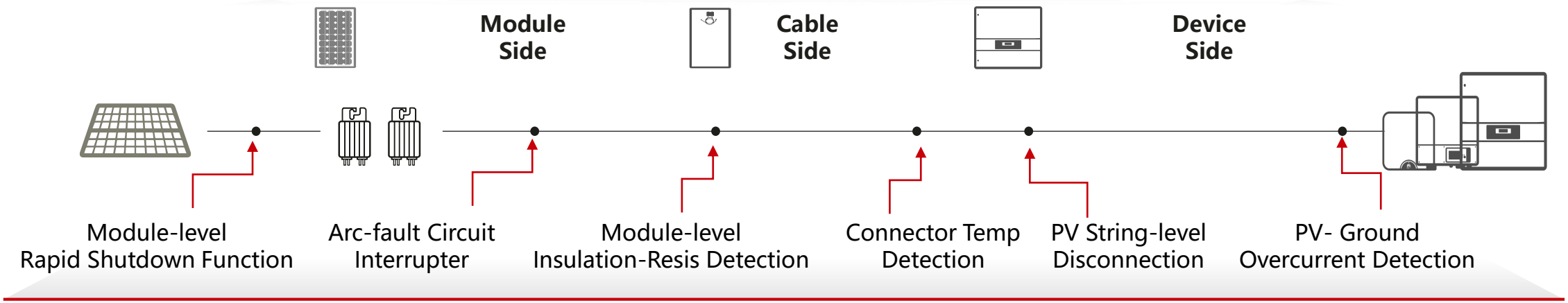
1995-2000:
Dual Relay Design

2000-2010:
RCD & Insulation Resist Detection

2010-2020: AFCI+RSD

2020-2030:
System-level Safety

System-level DC Safety Solutions



2

Challenges and Solutions (Modules)

PV Array Remains High Voltage Even If Disconnect

Personal Safety Becomes Main Concern of O&M Safety

- As long as the sun is here, the output voltage of a module **remains 45 V** when the PV cable is broken
- Traditional solar inverters use the manual string shutdown solution and for the voltage of the whole string will **remain 1100V**

Fire Accident in Thailand Telecom Center Building in March 2022

Impact: The fire in the building caused a direct economic loss of **US$100,000**.

Cause: The system did not have the RSD function. As a result, **the PV modules were still generating electricity while burning**, and the fire cannot be extinguished.
Thailand EIT refers to the test result of the UL lab in the US. High voltage still exists when PV modules are burning.

Recommendation 1: Extend the Module-level Rapid Shutdown Function and Standard to Ensure Personal Safety

Traditional solution: **String-level Shutdown** cannot disconnect high voltage between PV modules.

- As long as the light is here , the PV Array will remain DC high voltage, firefighters can not go to the roof to rescue and only wait for the PV module to burn finished before rescue

Recommend solution: Module-level Rapid Shutdown & Module-level Detection technology

- During installation and O&M, the optimizer disconnects the PV string voltage to “0V” to ensure the safety of personnel.
- In case of an emergency (such as a fire), RSD ensures that firefighters can go to the site for rescue in a timely manner to ensure personal and property safety.

RSD — Combination of Prevention and Firefighting to Ensure Rooftop Safety

PV systems pose fire safety risks

PV projects, particularly those installed in populous areas, have drawn major safety concerns.

Germany: The firefighter is explaining why they have to **let it burn** in the case of a rooftop PV fire.

They have to wait for the PV modules to burn before rescue to **avoid electric shocks**.

RSD ensures fire safety

Without RSD

Traditional rooftop PV systems have **DC high voltage** when there is sunlight. Even if the inverter is shut down, the DC voltage still exists and **cannot be reduced**. Firefighters have to wait until the PV modules are burnt before rescue.

With RSD

When the DC or AC side is disconnected,
the voltage of each PV module is rapidly reduced to **below the safe voltage**, so that firefighters can start rescue as soon as possible.

More Countries and Regions Are Adopting RSD Standards

China
Anhui Province: *Code for Fire Safety of PV System in Buildings*
Shanghai: *Technical Standard of Solar Photovoltaic System on Building*
Ministry of Housing and Urban-Rural Development: *Technical Regulations for Building-Integrated Intelligent Solar Photovoltaic System*
Dalian: *Code of Practice for Evaluation of Green Smart Building*
Germany VDE-AR-E 2100-712
Austria OEVE Directive R 11-1
US/Canada NEC 2017 690.12
NEC 2020 690.12
Mexico NOM-001-SEDE-2012
Brazil PORTARIA INMETRO 004
Thailand: EIT rooftop PV design specifications
The Philippines PEC 690.2.6 Rapid shutdown requirements

Europe: VDE-AR-E 2100-712 (fire safety standard) specifies that if the wiring terminals of rooftop PV modules are exposed on the rooftop, the RSD function must be provided.

US: The requirement on the RSD function of rooftop PV systems has been added to National Electrical Code (NEC) 2014. The standard has been updated every three years since 2014. The latest version, NEC 2020, has taken effect in 14 states.

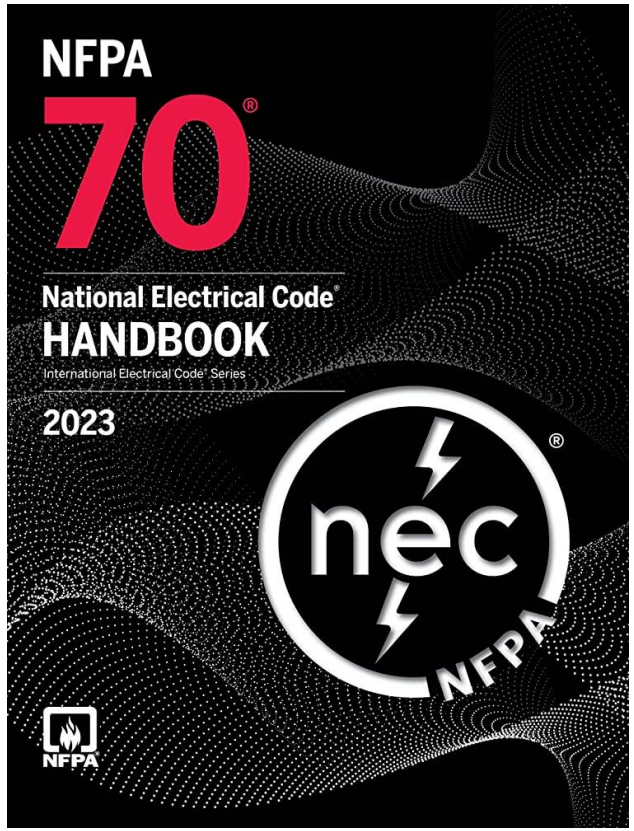
Thailand: EIT includes "rapid shutdown" into the rooftop electrical installation standard, which will be implemented in July 2023.

China: *Technical Specification for Connecting Residential Roof-top Photovoltaic System to Power Grid* released by Zhejiang Province and *Notice on Strengthening the Safety of Distributed PV Power Generation* released by China's National Energy Administration have stipulated that PV systems in buildings must be equipped with RSD devices.

Brazil: The **Inmetro RSD** safety standard will be released in 2024.

Global RSD Standards — US: NEC 690.12

US: NEC 690.12



2017 NEC 690.12: **Within 30 seconds** of rapid shutdown initiation, the voltages of controlled conductors located outside and inside the boundary (305 mm from the array in all directions) shall be limited to **less than 30 V** and **less than 80 V**, respectively. This means that **module-level shutdown** shall be implemented. This requirement has taken effect as of **January 1, 2019**.

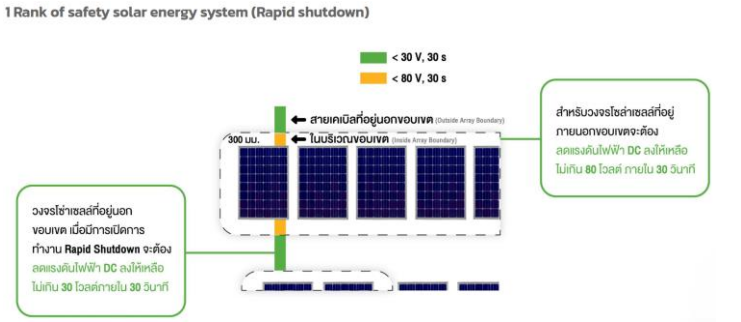
2014 NEC 690.12: **RSD switches shall be installed** for PV systems in all buildings. The PV system voltage shall decrease to **less than 30 V within 10 seconds**. However, RSD solutions compliant with this standard **do not achieve module-level shutdown** and DC high voltage still exists on rooftops (within PV arrays).

In addition, the voltage of the ELV circuit shall be less than or equal to 120 V DC according to section 4.2 in IEC 61140-1 Protection against electric shock – Common aspects for installations and equipment. That is, maintenance personnel are allowed to perform maintenance operations within **120 V DC**. The combination of NEC and IEC will make a great difference in PV system designs.

Global RSD Standards — Thailand

Thailand EIT

1	**หน้าที่** 44 4.3.13 **อุปกรณ์หยุดทางานฉุกเฉิน** (rapid shutdown) ระบบผลิตไฟฟ้าจากพลังงานแสงอาทิตย์ที่ติดตั้งบนหลังคา ต้องมีอุปกรณ์ที่ทำหน้าที่หยุดทำงานฉุกเฉิน ซึ่งมีคุณลักษณะ ดังนี้ (1) ลดแรงดันไฟฟ้าในบริเวณ Array boundary ให้เหลือไม่เกิน 80 โวลต์ ภายใน 30 วินาที หรือ ใช้อุปกรณ์ควบคุมเพื่อลดความเสี่ยงจากการเกิดไฟดูดในการเกิดอันตรายต่อพนักงานดับเพลิง ซึ่งต้องมีผลการทดสอบ ตามขั้นตอนหรือ ใบรับรอง ตามมาตรฐาน UL 3741 โดยรายงานผลการทดสอบต้องออกโดยสถาบันหรือหน่วยงานทดสอบที่เป็นกลาง และได้มาตรฐาน ได้แก่ TUV, VDE, Bureau Veritas, UL, CSA, InterTek หรือ PTEC	4.3.13 **อุปกรณ์หยุดทางานฉุกเฉิน** (rapid shutdown) ระบบผลิตไฟฟ้าจากพลังงานแสงอาทิตย์ที่ติดตั้งบนหลังคา ต้องมีอุปกรณ์ที่ทำหน้าที่หยุดทำงานฉุกเฉิน ซึ่งมีคุณลักษณะ ดังนี้ (1) ลดแรงดันไฟฟ้าในบริเวณ Array boundary ให้เหลือไม่เกิน 80 โวลต์ ภายใน 30 วินาที หรือ ใช้อุปกรณ์ควบคุมเพื่อลดความเสี่ยงจากการเกิดไฟดูดในการเกิดอันตรายต่อพนักงานดับเพลิง ซึ่งต้องมีผลการทดสอบ ตามขั้นตอนหรือ ใบรับรอง ตามมาตรฐาน UL 3741 โดยรายงานผลการทดสอบต้องออกโดยสถาบันหรือหน่วยงานทดสอบที่เป็นกลางที่ได้มาตรฐาน ได้แก่ TUV, VDE, Bureau Veritas, UL, CSA, InterTek หรือ PTEC


1 Rank of safety solar energy system (Rapid shutdown)
< 30 V, 30 s
< 80 V, 30 s
300 มม.
สายเคเบิลที่อยู่นอกขอบเขต (Outside Array Boundary)
ในบริเวณขอบเขต (Inside Array Boundary)
สำหรับวงจรโซล่าเซลล์ที่อยู่ภายนอกขอบเขตจะต้อง ลดแรงดันไฟฟ้า DC ลงให้เหลือไม่เกิน 80 โวลต์ ภายใน 30 วินาที
วงจรโซล่าเซลล์ที่อยู่นอกขอบเขต เมื่อมีการเปิดการทำงาน Rapid Shutdown จะต้อง ลดแรงดันไฟฟ้า DC ลงให้เหลือไม่เกิน 30 โวลต์ภายใน 30 วินาที

EIT requirements: Rooftop PV systems shall be equipped with RSD. **Within 30 seconds** of rapid shutdown initiation, the voltages of controlled conductors located outside and inside the boundary (300 mm from the array in all directions) shall be limited to **less than 30 V** and **less than 80 V**, respectively. This means that **module-level shutdown** shall be implemented.
Effective date: **2023-07-01**

According to the rooftop DC voltage and shutdown requirements, this standard is Thailand's version of NEC 2020 690.12.

3

Challenges and Solutions (Cables)

Arc Detection Challenges

Arc noise is generally weak and only accounts for 0.1% of the normal current signal, it is difficult to detect and often leads to missing detection

Inverter/Loads/Grid interference signals, as well as spectral overlay with normal current signal leads to faulty detection

Electric Arcing Is Threatening the Safety of PV System & Buildings

What is it?

- electrical breakdown of air that produces an prolonged electrical discharge

What causes Electric Arcing?

- Unreliable soldered joints within modules
- Broken PV cables
- Loosen PV connectors

What is the harm?

Can reach temperature of over 3000°C & easily start a fire

What is An Arc?

- An arc is a glow phenomenon caused by the ionization of the air when an electric conductor is close to another conductor (or ground) and the voltage between them breaks down the air.

E = K x (U/d)

Note:

E (electric field strength)

U (voltage)

d (distance)

K (coefficient)

→ The arc strength is closely related to the **voltage difference between conductors** and the **distance between conductors**.

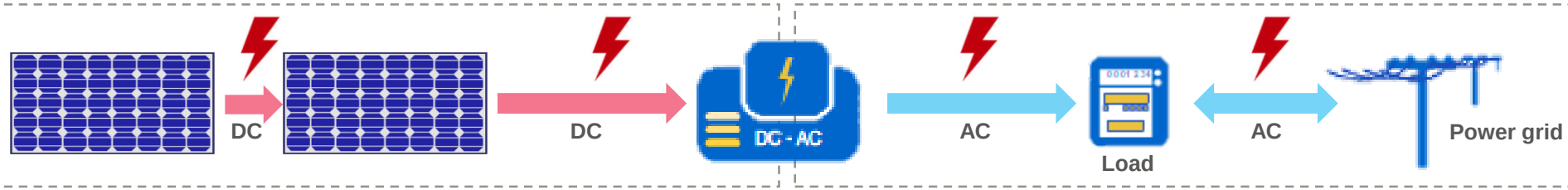
* Lightning is a type of arcs with great energy.

- Arc is one of the most serious but least known electrical hazards. It is generally caused by technical faults of electrical equipment, such as improper installation, dust, corrosion, surface impurities, and even normal wear and tear. Electric arc can cause many dangerous secondary hazards, such as **fire, electric shock, melted metal splashes,** etc.

DC Arcs Are Difficult to Extinguish and Cause High Temperature, Posing Safety Risks to a PV System

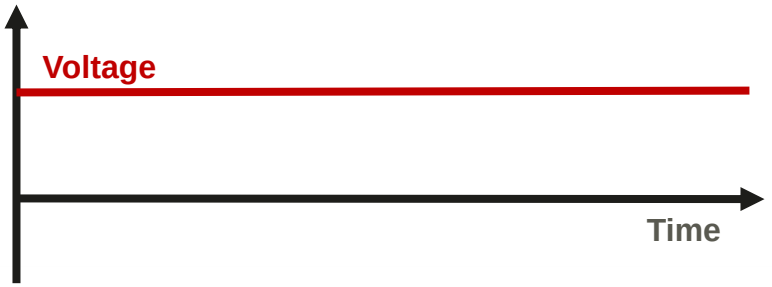
Arcs in a PV system

The PV system involves both DC and AC sides, and arcs may be generated on both sides.



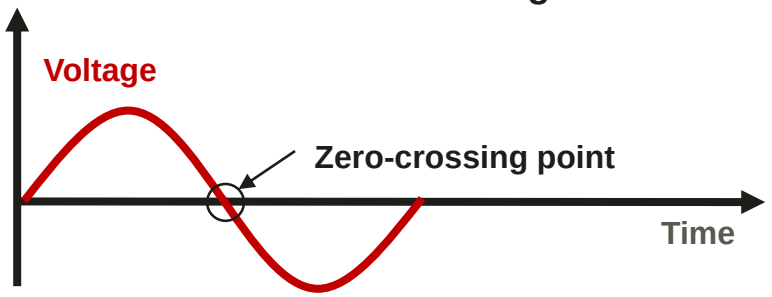
DC arc

The voltage of the DC system is constant. Unless affected by external factors, **the DC arcs cannot be extinguished**.



AC arc

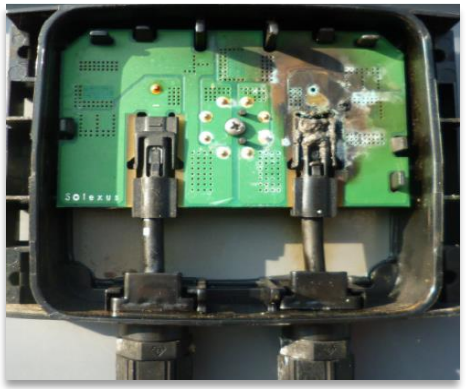
The values and directions of the AC voltage and current change periodically. At the **zero-crossing point**, no current exists in power cables and **the AC arcs are extinguished naturally**.



DC arcs are **more difficult to extinguish and cause higher temperature** than AC arcs.
Therefore, the fire risk of DC arcs is far greater than that of AC arcs in a PV system.

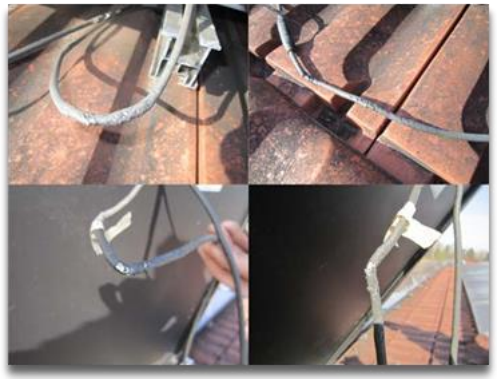
Three Common Causes of DC Arcs in a PV System

Unreliably-welded PV junction boxes



Incompatible connectors or unreliable connections

Damaged DC cables due to aging



Fire and O&M Risks Caused by DC Arcs

Fire caused by high-temperature arcs

DC arcs can reach a temperature higher than 3000°C, causing fire on the rooftop.

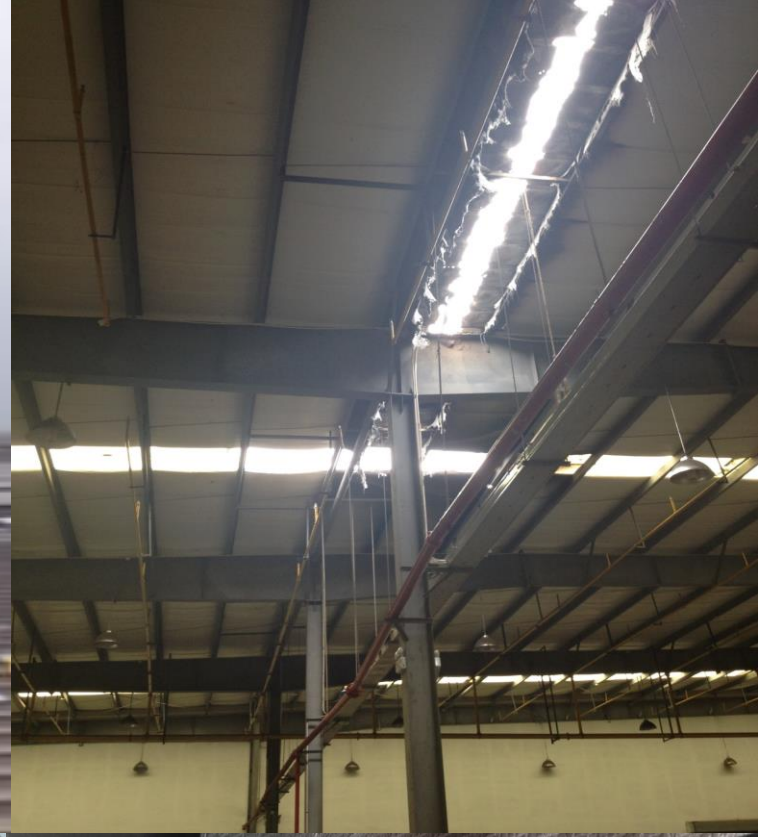
O&M risks caused by high voltage and current

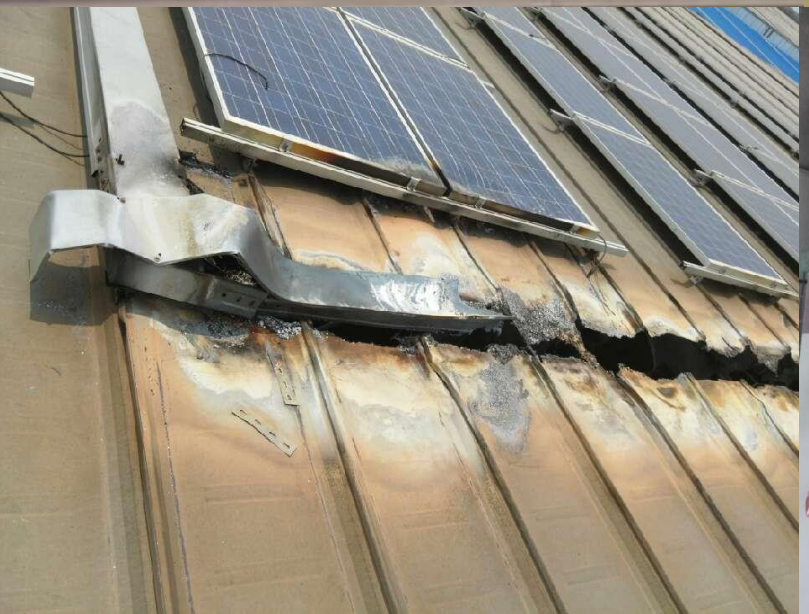
DC high voltage (700–800 V) and current (20 A) put installers and firefighters at risk.

Residential Rooftop PV Fire Accident in London, UK

Impact: In 2017, a PV fire occurred in London, UK and damaged a total of **5 houses** and **18 apartment buildings**, each worth nearly **1 million pounds**.

Cause: After analysis, the root cause of the fire is that the **terminals were loosely connected** during PV module installation. However, it is difficult to maintain and manage residential PV systems and safety inspection is rarely carried out. Therefore, solving safety risks of arcs is a pressing demand.





Factory PV Fire Accident in Wuhan, China

Impact: In August 2014, the rooftop PV plant of a factory in Wuhan caught fire. The rooftop of color steel tiles was burnt through with several large holes, and **several devices in the factory were burnt**, **causing heavy losses**.

Cause: **The cables of a combiner box were damaged** due to construction, which was further aggravated by the circulating current and leakage current. As a result, the insulation failed, and short circuits and arcs occurred on the cables in the cable trough, causing the fire.

According to statistics, more than 80% of fire accidents in PV plants are caused by **faults on the DC side**, especially the PV module hotspots, DC short circuits, quality problems of the DC power distribution cabinet, and fuse problems. In rooftop plants, DC arcs are inevitable, because there are thousands of connectors in the entire plant and poor contact of any connector may cause DC arcs, resulting in fire. This is a pain point in PV plant safety.

Fire After Typhoon at Japan's Largest Floating PV Plant in Chiba Prefecture, Tokyo

Impact: In September 2019, Japan's largest floating PV plant caught **fire**, which did not cause injuries. Located in Chiba Prefecture near Tokyo, the floating PV plant has more than 50,000 solar panels and covers an area of about 18 hectares.

Cause: The fire was started from **DC bus cables**. As shown in the figure on the left, traces of fire were found on the DC bus cables. It was concluded that the fire was caused by the DC power cable short circuit. **Arcs** must have occurred, because common DC short circuits will not produce such heat that can melt metal.

Walmart Rooftop PV Fires

Impact: At least seven Walmart stores encountered fires caused by PV systems between 2012 and 2018.

Cause: According to the lawsuit filed by Walmart, the fire was caused by poor installation quality and/or poor maintenance of leased PV modules. Many problems have been located, including hotspots on PV modules, **loose connectors**, and **incorrect grounding** during installation.

— from mtvSolar on September 17, 2019

Inspections found that several **solar panels were broken and that wires were hanging out**, causing a fire hazard...

"**Wires on the store's rooftop were still sparking** at the time that Walmart discovered the fire and could have ignited more extensive flames, with potentially devastating consequences," the lawsuit claims.

— from CBS NEWS on August 21, 2019

Recommendation 2: Use the Accurate AFCI solution to ensure the safety of property

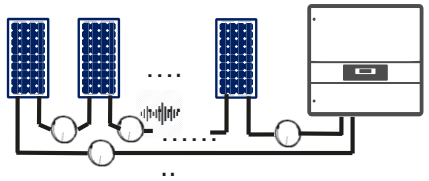
Traditional External AFCI Solution:

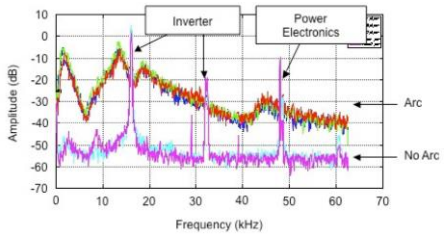
High Investment and Maintenance Costs

- Additional AFCI external case required
- Poor compatibility between system components

Traditional built-in AFCI solution:

Frequent Tripping Makes More Complain

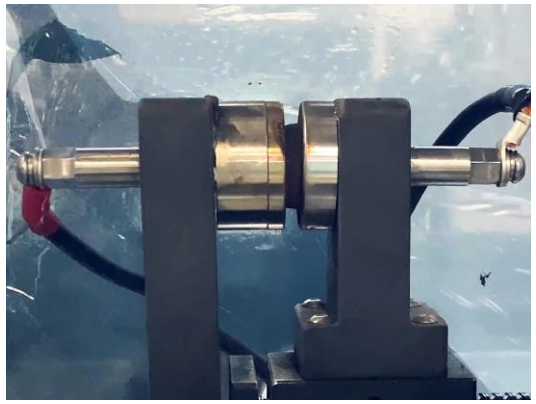


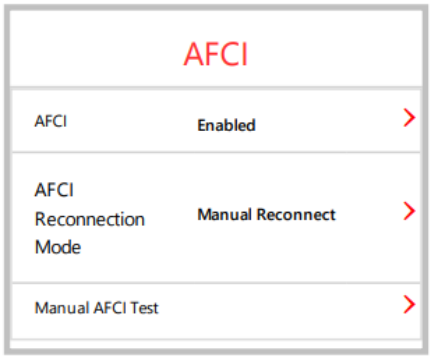


- Frequent system tripping reduces system availability, resulting in reduced power generation and revenue
- Arc Fault Missing Detection Can't Guarantee System Safety

Recommend solution:

AFCI function enabled, arcing extinguished in 0.5s





- Built-in Stability Solution for optimal investment costs
- Precise positioning, 100% identification disconnection
- Detection distance > 200 m, covering 99% of rooftops
- Max detection range > 30 A, Support All kinds of PV modules
- Fastest shutdown speed < 0.5s, minimum energy release

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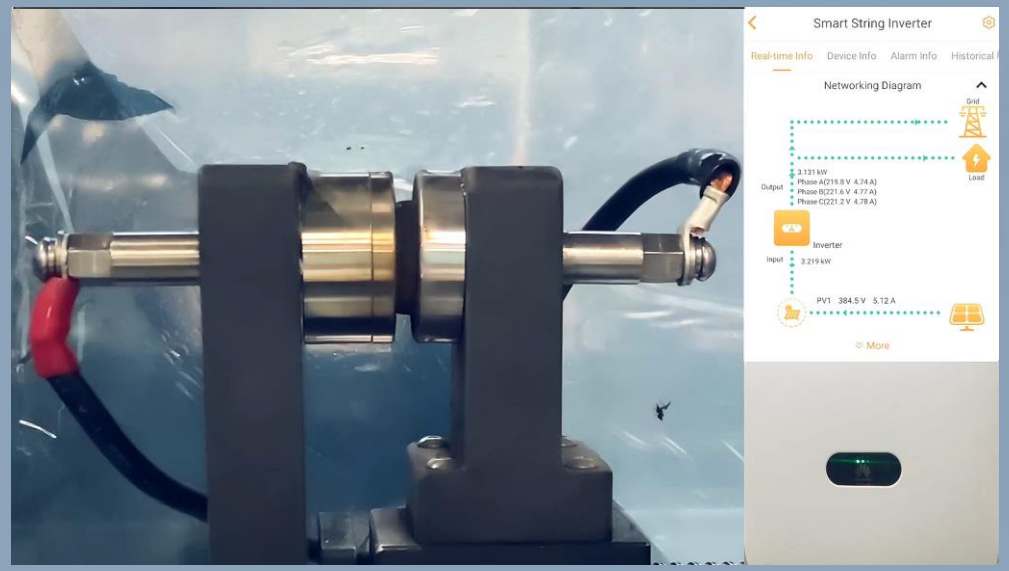
AI BOOST

AFCI disabled, arcing continuously posing fire risks



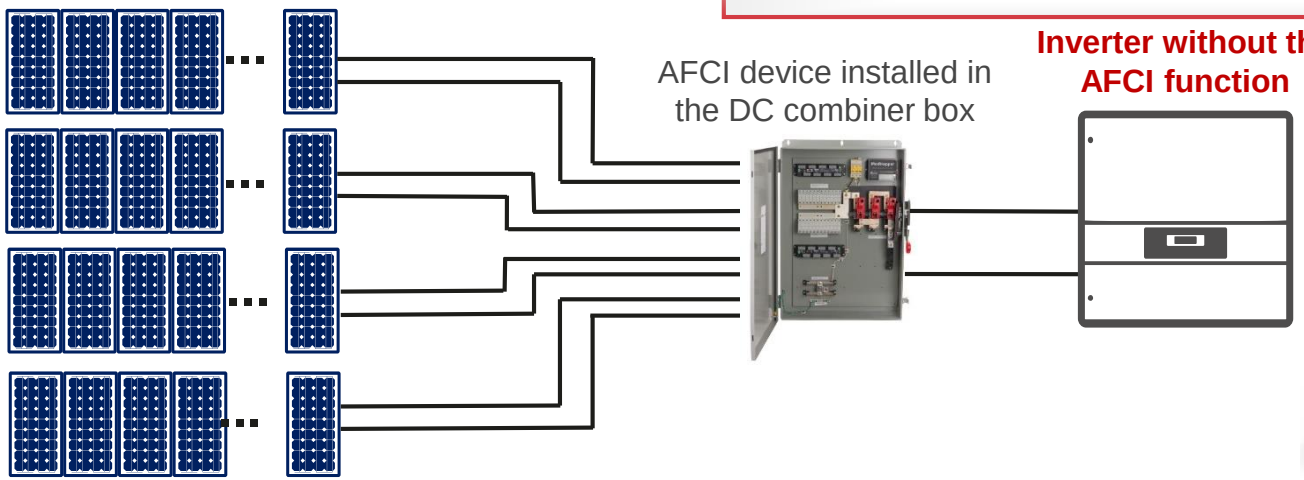
VS

AFCI function enabled, arcing extinguished in < 0.5sec

PV Arcing with/without AFCI Comparison

Implementation of Arc Fault Detection (AFCI*)

Inverter with an external AFCI



AFCI device installed in the DC combiner box

Inverter without the AFCI function

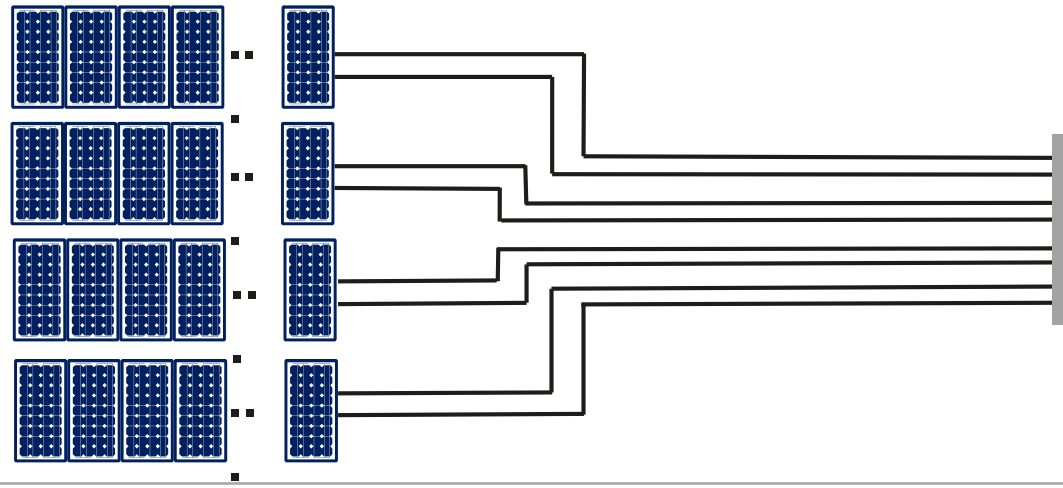
For inverters without the AFCI function, an independent DC arc fault circuit breaker is usually selected and installed in the DC combiner box of the PV system.

- Investment and maintenance at a **high cost**
- System components with **poor compatibility**

Product	Unit Price
Combiner box with an arc detector	**US$150**

Inverter with a built-in AFCI

- Ensuring **system safety**
- Initial investment and maintenance at a **low cost**
- Standards compliance



Inverter with a built-in AFCI

* AFCI refers to PV arc-fault circuit interrupter.

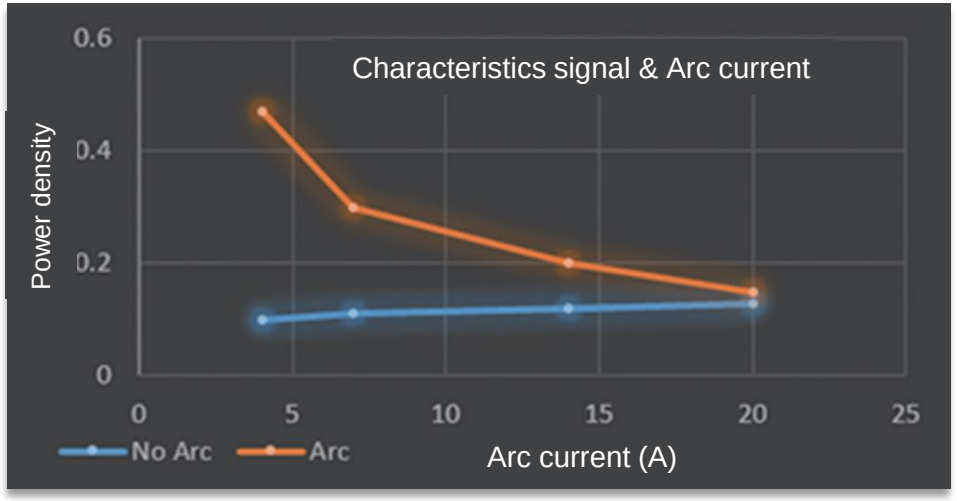
Two Challenges for Arc Fault Detection: Variable Environmental Noise and High Usage Requirements

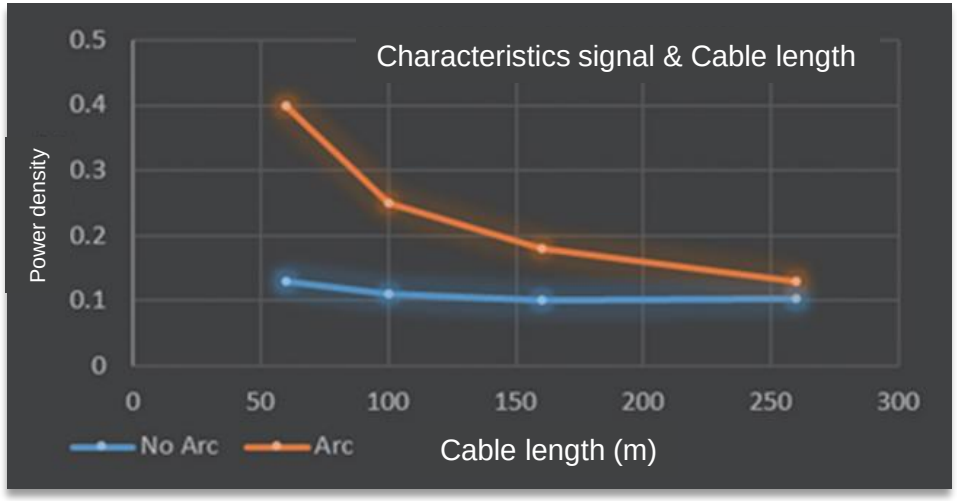
Challenge 1: Various operating environment and variable environmental noise make it difficult to identify arcs.

- The onsite operating environment of the device is complex and variable. The arc detection algorithm and threshold setting are mainly based on human experience. When the environment noise is close to the arc spectrum characteristics, it is difficult to distinguish them, which may cause false alarms and shutdowns.

Challenge 2: In actual application scenarios, the cable length and arc current on the DC side exceeds the standard testing condition.

- For example, for 100 kW or higher inverter solution designs for the commercial and industrial (C&I) rooftops, the input cable length may reach hundreds of meters, and the maximum arc current may exceed 20 A.
- With the increase of current and cable length, the characteristic signal of arcs gradually weakens, which raises higher requirements for the precision of detection instruments and algorithms.





The cable length, current, arc energy, and arc extinguishing protection time must meet the application scenario requirements based on IEC 63027. The requirements must be described in the user manual.

Low Detection Precision Causes AFCI False Alarms and Missed Detections, Bringing Troubles to Installers and Owners

Installer: Frequent false alarms lead to many complaints and frequent site visits, increasing O&M workload.

- Customers complain about false alarms and tripping, which distract installers from business development and **affect customers' evaluation on installers.**
- Frequent site visits **increase the maintenance workload and costs**.

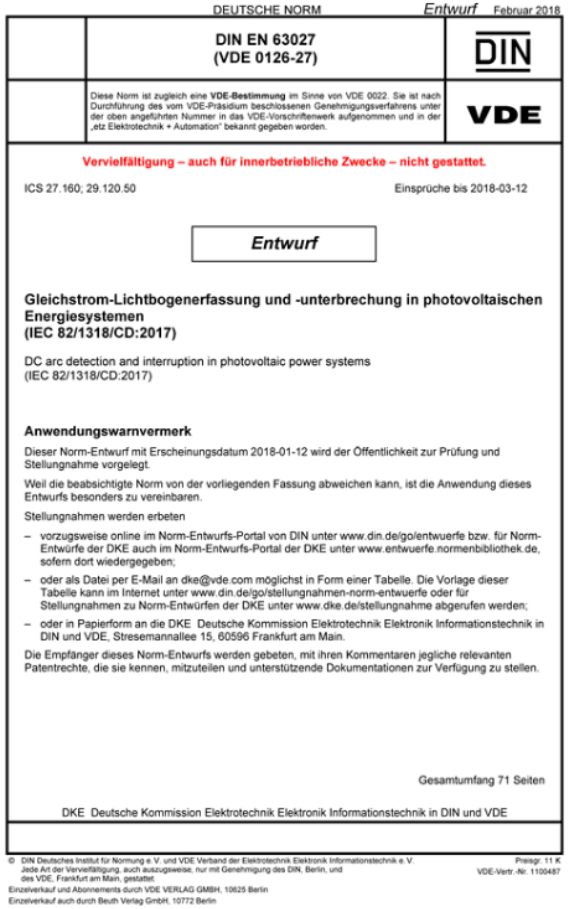
Customer: Frequent false tripping affects energy yields of the system and missed detections cannot ensure system safety.

- Frequent false tripping reduces system availability, thereby **reducing energy yields and revenues**.
- **Missed detections of arc faults** cannot ensure safety and the system is prone to major accidents such as fire, causing property loss and adverse social impact.
- Frequent manual checks and site visits result in high O&M costs.

The AFCI function is enabled by default to improve the AFCI alarm accuracy, which strictly meets the IEC 63027 test requirements.

Global Arc Fault Protection and AFCI Standards — EU: IEC 63027

EU: IEC 63027



DEUTSCHE NORM *Entwurf* Februar 2018

DIN EN 63027
(VDE 0126-27)

DIN

VDE

Diese Norm ist zugleich eine **VDE-Bestimmung** im Sinne von VDE 0022. Sie ist nach Durchführung des vom VDE-Präsidium beschlossenen Genehmigungsverfahrens unter der oben angeführten Nummer in das VDE-Vorschriftenwerk aufgenommen und in der „etz Elektrotechnik + Automation" bekannt gegeben worden.

Vervielfältigung – auch für innerbetriebliche Zwecke – nicht gestattet.

ICS 27.160; 29.120.50 Einsprüche bis 2018-03-12

Entwurf

Gleichstrom-Lichtbogenerfassung und -unterbrechung in photovoltaischen Energiesystemen
(IEC 82/1318/CD:2017)

DC arc detection and interruption in photovoltaic power systems
(IEC 82/1318/CD:2017)

Anwendungswarnvermerk

Dieser Norm-Entwurf mit Erscheinungsdatum 2018-01-12 wird der Öffentlichkeit zur Prüfung und Stellungnahme vorgelegt.

Weil die beabsichtigte Norm von der vorliegenden Fassung abweichen kann, ist die Anwendung dieses Entwurfs besonders zu vereinbaren.

Stellungnahmen werden erbeten

- vorzugsweise online im Norm-Entwurfs-Portal von DIN unter www.din.de/go/entwuerfe bzw. für Norm-Entwürfe der DKE auch im Norm-Entwurfs-Portal der DKE unter www.entwuerfe.normenbibliothek.de, sofern dort wiedergegeben;
- oder als Datei per E-Mail an dke@vde.com möglichst in Form einer Tabelle. Die Vorlage dieser Tabelle kann im Internet unter www.din.de/go/stellungnahmen-norm-entwuerfe oder für Stellungnahmen zu Norm-Entwürfen der DKE unter www.dke.de/stellungnahme abgerufen werden;
- oder in Papierform an die DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE, Stresemannallee 15, 60596 Frankfurt am Main.

Die Empfänger dieses Norm-Entwurfs werden gebeten, mit ihren Kommentaren jegliche relevanten Patentrechte, die sie kennen, mitzuteilen und unterstützende Dokumentationen zur Verfügung zu stellen.

Gesamtumfang 71 Seiten

DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE

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- It aims to solve the problems of series arc fault detection and interruption when the DC voltage in the PV system does not exceed the maximum PV source circuit voltage of **1500 V DC**.
- It covers the test procedure for detecting **series arcs** in PV circuits, as well as the **response time** of devices used to interrupt arcs.
- It defines the reference scenarios for tests. This standard covers equipment connected to a maximum PV source circuit voltage of 1500 V DC, excluding detection of parallel circuit arcs.

* AFCI refers to PV arc-fault circuit interrupter.

IEC 63027 — Arc Fault Detection and Interruption Test, Requiring the System to Identify or Interrupts Arcs Within 2.5 Seconds

Arc test conditions defined in IEC 63027:

Current (A)	Operating Voltage (V)	Open-Circuit Voltage (V)	Rate (mm/s)	Clearance (inches)
2,5	312,0	480,0	2,5	0,8
7,0	318,0	490,0	5,0	0,8
14,0	318,0	490,0	5,0	1,1
7,0	607,0	810,0	5,0	2,5
0.9 x I_{PA}	318,0	490,0	5,0	2,5

The **total arc time** before the device under test **detects** or interrupts the arc shall not exceed the smaller value of the following two items:

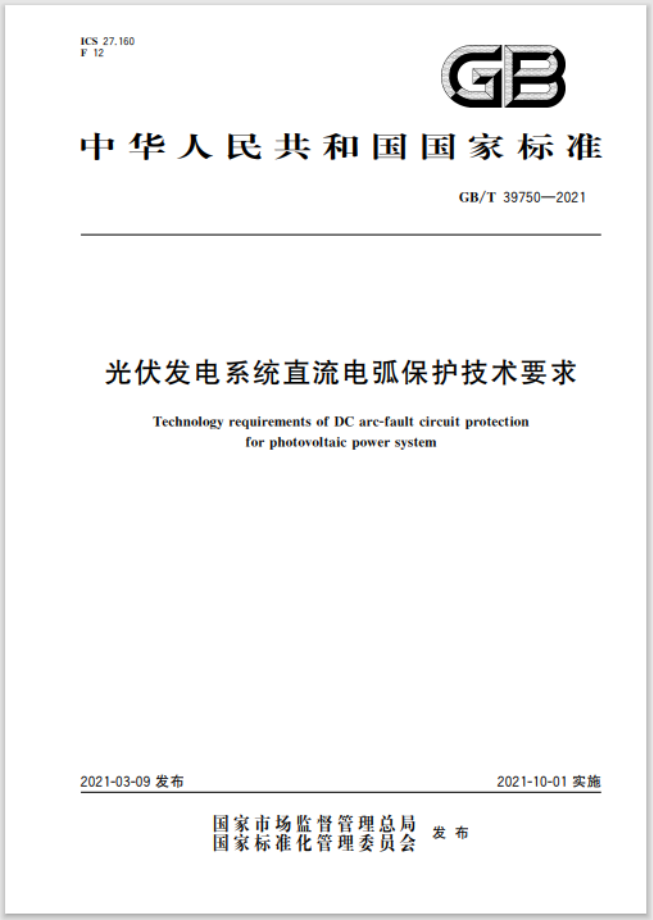
- **2.5 seconds** continuous arc discharge; or
- **750 joules** divided by the product of the measured arc current (amperes) multiplied by the measured arc voltage (volts), in seconds.

$$t = \frac{750\,J}{I \times V}$$

The test system shall be equipped with a DC conductor whose total length is **80 m**, including the cables of 10 PV modules in the PV string.

Global Arc Fault Protection and AFCI Standards — China: GB/T 39750

China: GB 39750



ICS 27.160
F 12

中华人民共和国国家标准

GB/T 39750—2021

光伏发电系统直流电弧保护技术要求

Technology requirements of DC arc-fault circuit protection for photovoltaic power system

2021-03-09 发布　　2021-10-01 实施

国家市场监督管理总局
国家标准化管理委员会　发布

- It specifies the **basic regulations**, **requirements for protection devices**, and **protection modes and tests** of DC arcs in PV power systems.
- For building integrated PV power systems, if the maximum system voltage on the DC side is **greater than or equal to 80 V**, DC arc protection measures are recommended.
- The response time of the protection device shall be **less than 2.5 seconds** after an arc occurs when the arc energy is less than **750 Joules**.

Global Arc Fault Protection and AFCI Standards — US: UL 1699B

US: UL 1699B

There are requirements for **AFCI devices** and **DC arc interruption time**.

UL 1699B

STANDARD FOR SAFETY

Photovoltaic (PV) DC Arc-Fault Circuit Protection

UL COPYRIGHTED MATERIAL – NOT AUTHORIZED FOR FURTHER REPRODUCTION OR DISTRIBUTION WITHOUT PERMISSION FROM UL

	UL 1699B-2011	UL 1699B-2018
Arc type	Series arcs, or series and parallel arcs (no mandatory requirement)	Series arcs
Cable length	61 meters	50 uH + 0.7 uH per meter above 80 meters
Capacitance to ground		Positive and negative 1 nF
Protection threshold	The arc lasts for less than 2 seconds, and the arc energy is less than 750 joules.	The arc lasts for less than 2.5 seconds, and the arc energy is less than 750 joules.
Fault rectification	Manual rectification	1. Automatic rectification after a delay of 5 minutes 2. Manual rectification 3. Manual rectification when five such faults occur within 24 hours
Fault location	Input side	Input side and between PV modules

- UL 1699B specifies the specific test conditions and methods for arc fault detection and interruption.
- This standard requires that PV AFCI devices be able to detect arcs of **300 W or higher** and interrupt arcs **within 2.5 seconds** (only for **series arc faults**).

Insulation impedance is the main cause of Frequent of inverters Fault alarms in Rainy Season

What is insulation impedance?

Insulation impedance is equivalent to a resistance with the same resistance value between the sensor bridge and the ground.

For the inverter, when the insulation impedance is less than 0.5 MΩ,
the inverter stops connecting to the grid.

Cable Broken

Wet Environment

Suggestion 3: Use the Module-level Insulation Resist Detection to improve the precision, ensuring personal safety

Traditional Solution: Insulation Resis Detection Remains Disabled because of Hard O&M

- Traditional Insulation Impedance Detection solutions are **easily affected by external factors** such as humidity and temperature, resulting in **high proportion of Fault alarm and inaccurate location**
- . As a result, **O&M is complex and time-consuming** so the insulation resis detection function is often disabled, **causing electric shocks potential**

Recommended solution: Upgrade the insulation detection solution to the Module-level insulation detection solution

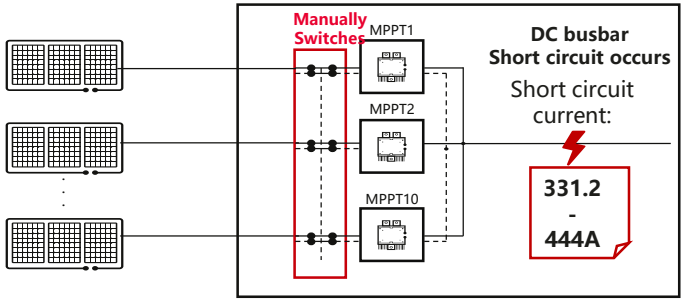
- **Adopts better detection hardware diagram** and forms to improve the insulation impedance detection precision and **improve the precision in complex weather**
- The built-in **Module-level detection solution** is used **to improve the detection precision, locate faults**, preventing potential risks caused by poor resis faults.

4

Challenges and Solutions (Device)

Device level damage:
Inverter, MCCB & transformer
Impact of secondary disasters: fire, etc.
(caused by surrounding combustibles)

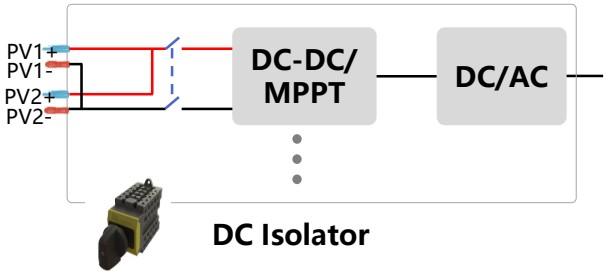
As the current increase of PV modules, the energy density of single point also increases Therefore, the equipment safety must be ensured to avoid secondary disasters



The DC side current is directly connected to the inverter bus capacitor, and the energy is easy to accumulate, causing device damage.

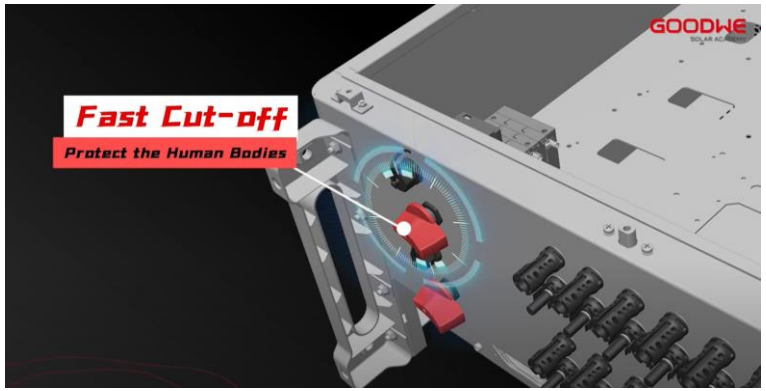
Suggestion 4: Use the string-level Disconnect Solution to automatically shut down the PV module ensuring device Safety

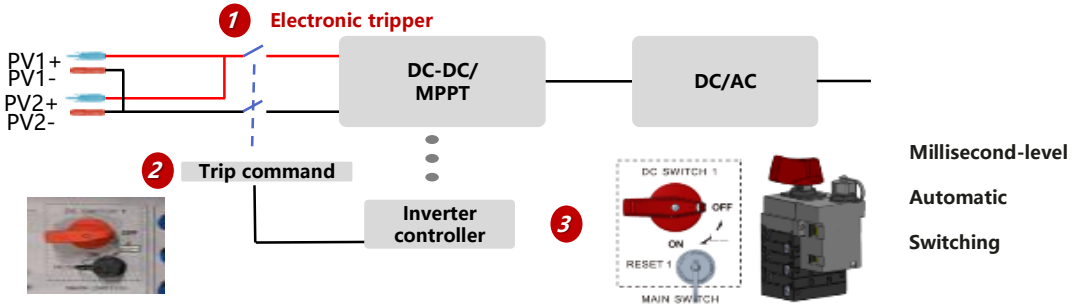
Traditional Solution:
Only manual disconnection



- Traditional inverter always choose isolator for PV side disconnection which can guarantee the high current of short circuit current.
- However, for dc isolator, it can only be manually switched off. So it is not easily to be tripped to against the sudden accident

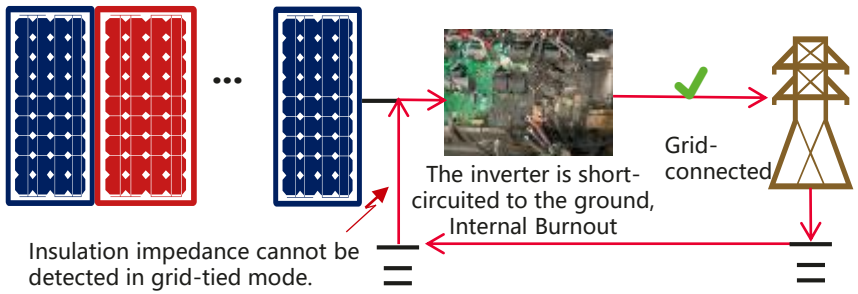
Recommended solution:
Adopt the Millisecond-level Automatic Switching Method



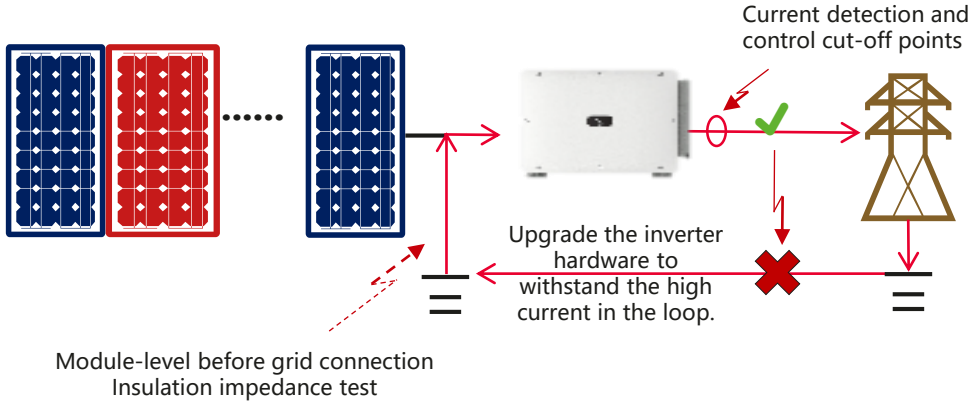


Suggestion 5: Adopt DC-to-ground protection, cut off ground faults within 15 ms during grid connection to ensure device safety

Traditional solution:
No method to protect inverter during on grid situation

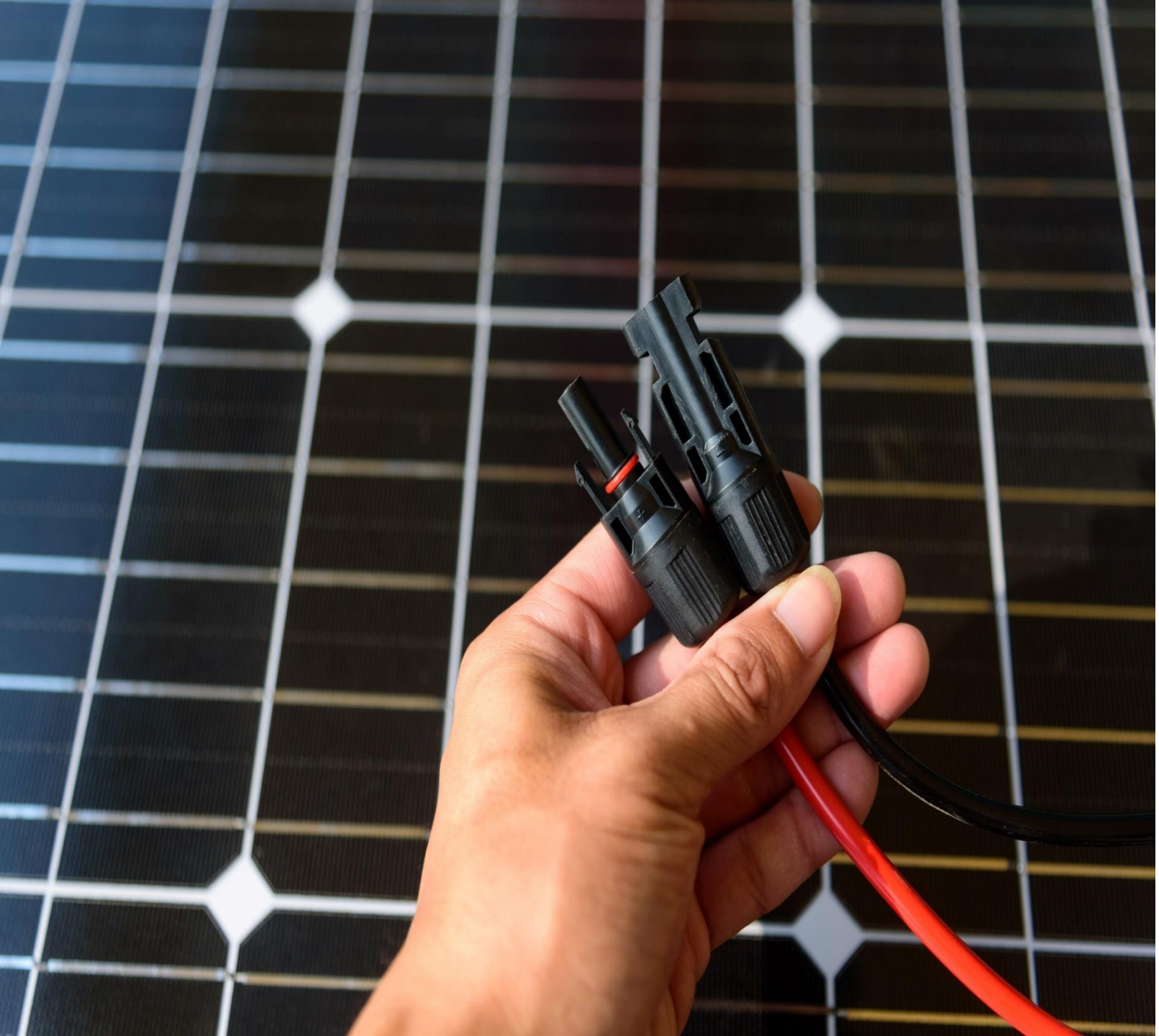

Grid-connected
The inverter is short-circuited to the ground, Internal Burnout
Insulation impedance cannot be detected in grid-tied mode.

Recommended solution: DC-to-ground protection needs to be added for the inverter


Current detection and control cut-off points
Upgrade the inverter hardware to withstand the high current in the loop.
Module-level before grid connection Insulation impedance test

- For traditional inverters, **insulation detection only works during installation**
- Having connected to the grid, only leakage current detection is used to assist insulation detection. When the **insulation impedance changes suddenly** due to external problems, the **inrush current** is easy to impact the AC bridge and DC busbar directly, resulting in **device damage**. If there are flammable or personnel around the equipment, secondary disasters may occur.

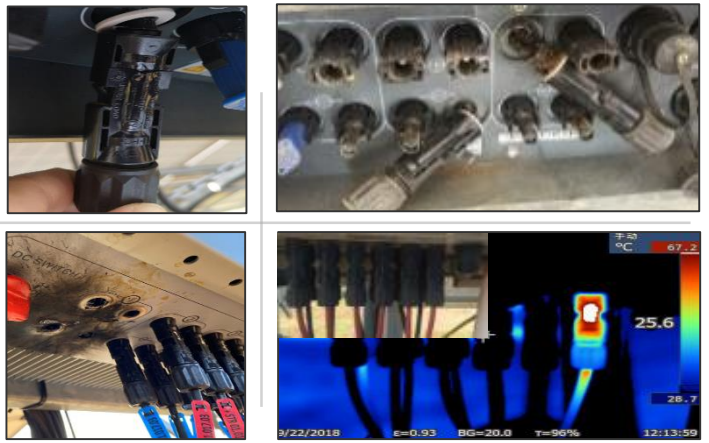
- Software algorithm: **detects the current** and Cut off Inrush current in **15 ms**
- Hardware improvement: Optimize the **short-circuit capability of inverter** and provide **overcurrent protection capability** for AC bridges



Short circuit, overcurrent, or false connection of wiring terminals may cause overheating of terminals and fire

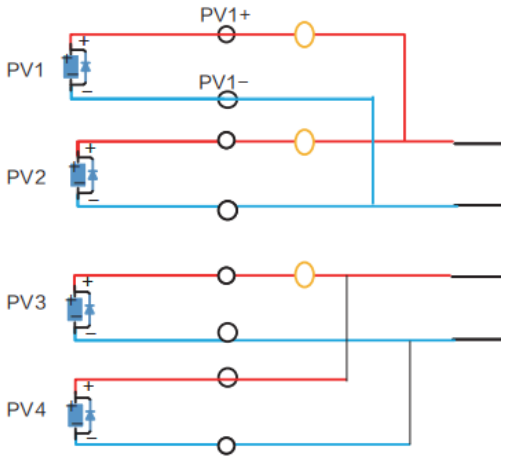
What are the causes of terminal short circuit & overcurrent?

- Cable connection is not standard.
- Ground subsidence pull cable
- Long-term use leads to component aging and loose contact.



Suggestion 6: Add Connector temperature Detection solution on the DC side to detect the temperature, ensuring device Safety

Traditional solution:
terminals are easily under virtual connection
however no detection solution is available to adjust



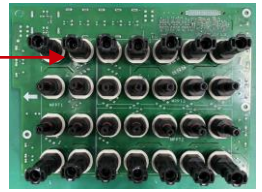
There are three reasons to cause virtual connection:

- The terminals are not usually properly connected
- The metal core is not properly crimped
- The contact is poor due to external forces.

Recommended solution:

Add Over Temperature Detection solution to inverter

PCB
+
NTC



NTC Sensor can be added through the upper board design (PCB Design)
Real time Connector Overtemperature detection, Ensuring DC side safety

Thank you.

把数字世界带入每个人、每个家庭、
每个组织，构建万物互联的智能世界。

Bring digital to every person, home and organization for a fully connected, intelligent world.

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HUAWEI

1

Huawei Overview

Huawei: Leading provider of ICT infrastructure and smart devices

207,000 employees

55% employees work in R&D

170+ countries and regions

No. 5 in global R&D investment

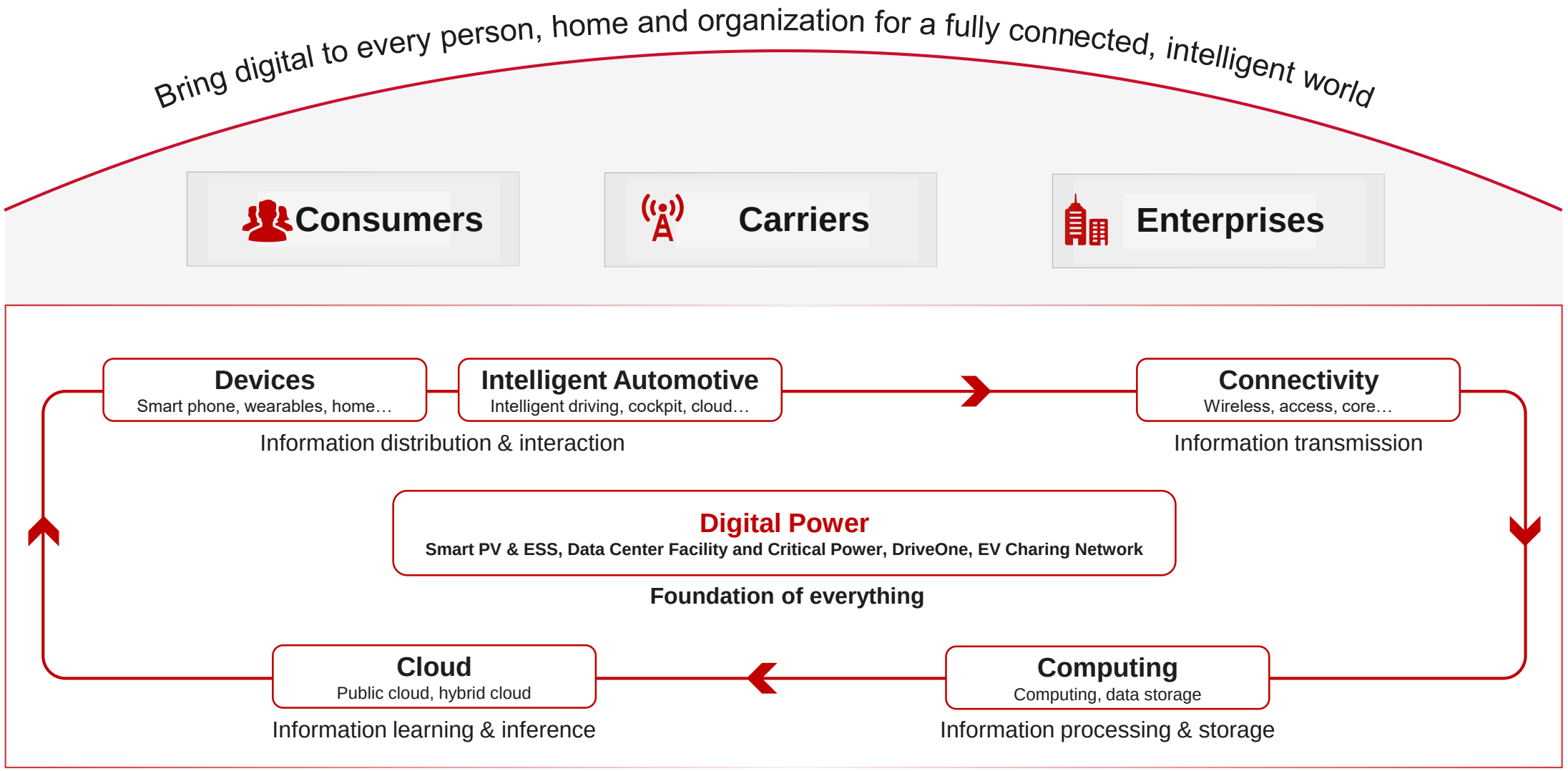
140,000+ active patents held globally

Vision & mission

Bring digital to every person, home and organization for a fully connected, intelligent world

HUAWEI

Focusing on Technology, Solutions, and Services to Three Customer Groups



HUAWEI

2023 Performance in line with forecast

2023 revenue: CNY704.2 bn (YoY ↑ **9.6%**)

Cloud computing business

CNY55.3 bn (YoY ↑ **21.9%**)

Achieving strong growth
Becoming the preferred cloud provider for industry customers

Digital power business

CNY52.6 bn (YoY ↑ **3.5%**)

Growing steadily
Helping customers go low-carbon

IAS business

CNY4.7 bn (YoY ↑ **128.1%**)

Delivering at scale
Leading intelligent transformation of the automotive industry

ICT infrastructure business

CNY362 bn (YoY ↑ **2.3%**)

Remaining solid
Continuously enhancing digital infrastructure

Consumer business

CNY251.5 bn (YoY ↑ **17.3%**)

Meeting expectations
Booming HarmonyOS ecosystem

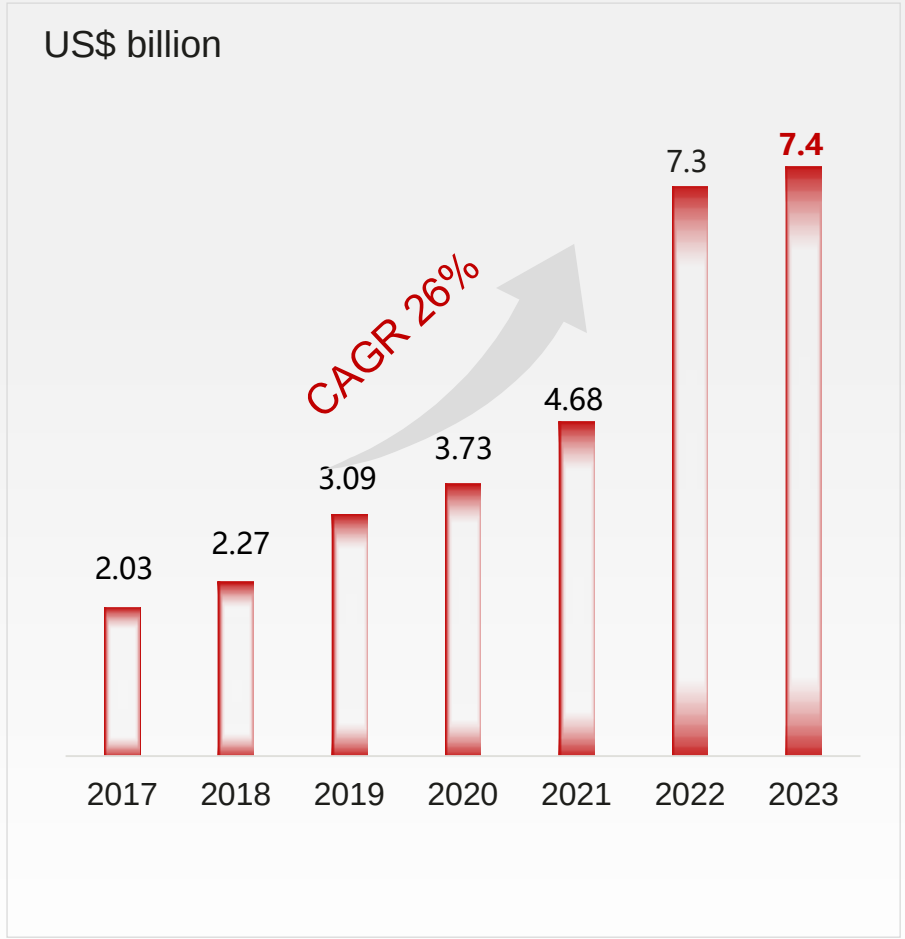
Note: Business-specific revenues include intercompany transactions and thus amount to more than Huawei's total revenue.

Source: 2023 Annual Report of Huawei Investment & Holding Co., Ltd.

HUAWEI

Steady growth of digital power businesses

Stable business growth



Integrating digital and power electronics technologies to promote green transformation in the industry

Smart PV: FusionSolar Grid-Forming Solution increasing renewables penetration by **40%**; inverters ranked **No. 1** globally by market share for 8 consecutive years

(Source: Wood Mackenzie)

Smart Charging Network: Fully liquid-cooled ultra-fast charging solution deployed in **50+** cities and along **20+** expressways including the G318 Highway

DriveONE: DriveONE eMobility solution adopted in **50+** vehicle models by **10+** automobile manufacturers

Data Center Facility & Critical Power: Modular UPS and FusionModule2000 ranked **No. 1** globally for 7 and 5 consecutive years respectively

(Source: Frost & Sullivan)

Site Power Facility: ranked **No. 1** globally by market share for 11 consecutive years

(Source: Frost & Sullivan)

HUAWEI

Global R&D Platforms: Leveraging the Continuous Investment to Keep Leading

>23% Annual R&D investment

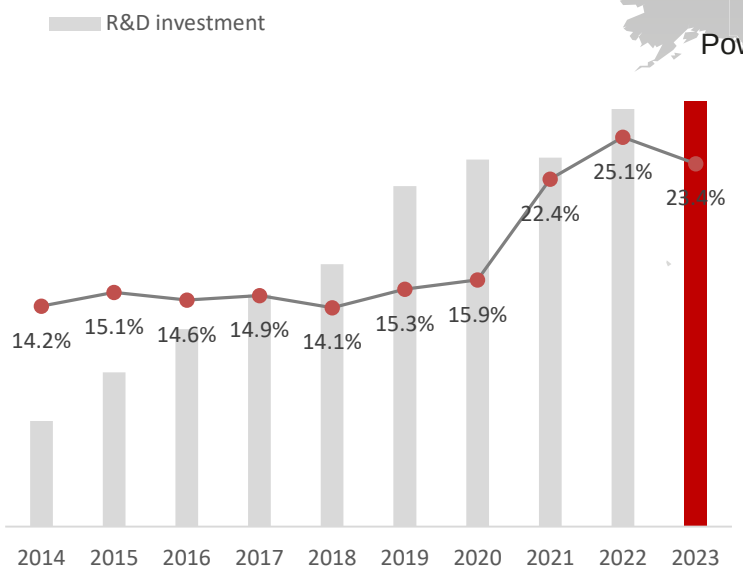
US$154 bn
R&D expenses over the past 10 years

US$ 23 bn
R&D expenses in 2023

200+
agreements with major industry patent holders

140,000+
Active patents

12
R&D centers

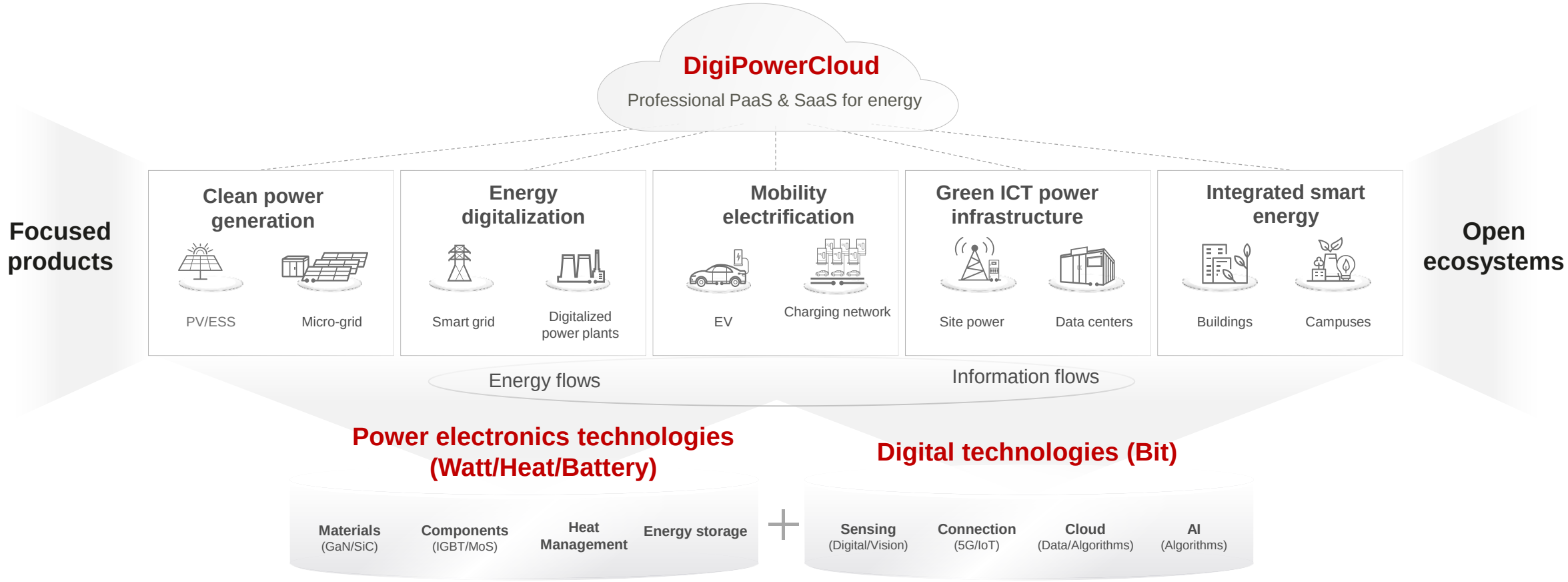


Huawei Proprietary - Restricted Distribution

Huawei Digital Power

Integrating Digital and Power Electronics Technologies, Developing Clean Power, and Enabling Energy Digitalization to Drive Energy Revolution for a Better, Greener Future

Evolving from high carbon to low carbon, and finally to net-zero carbon



HUAWEI

Huawei Philippines: Most Trustworthy Partner for Customers

Bring digital power to all industries, thousands of islands, millions of households, and work together to build a green digital Philippines.

No. 96
in Fortune Global 500

No. 4
in R&D investment

170+
countries and regions

207,000
employees

55.4%
R&D employees

Huawei Philippines

Established in 2002

2000+ staff 60% local staff

9 Offices covering 5 Regions

Based in Makati & BGC

472M $
Local Procurement Paid

92.8M $
Local Tax Paid

22,000+
Local Jobs Created

HUAWEI

Construct a Local Platform to Support Industry Development

Huawei In Philippines 20+ Years

Established in 2002, 2000+ staff

9 Offices covering 5 Regions

Based in Makati & BGC

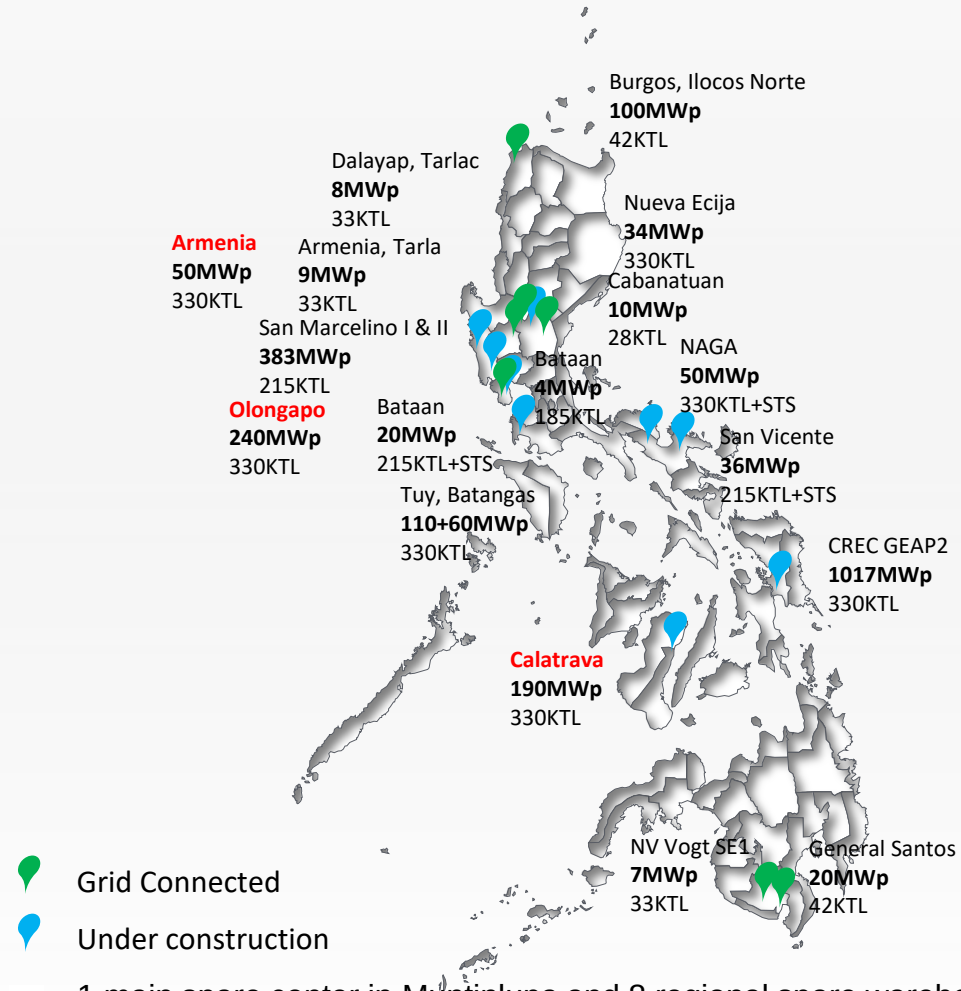
Success Starting From 2015

6MW utility in Cabanantuan

The Biggest project In PH

383MW in San Marcelino

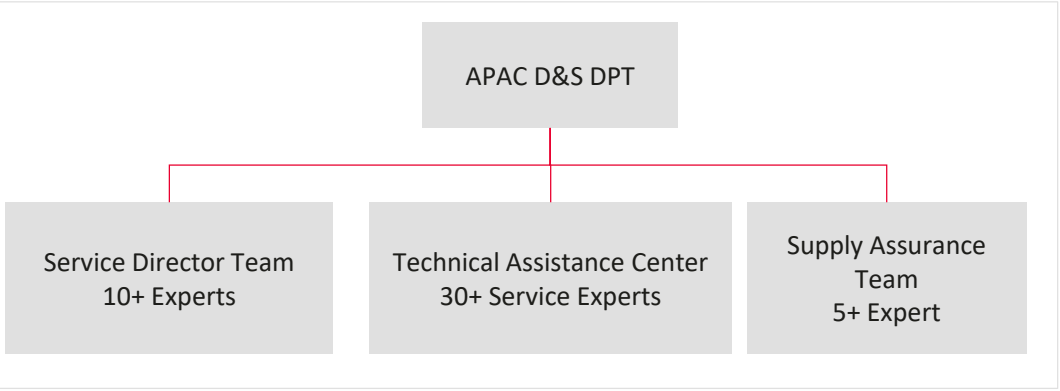
>2GW Inverter Shipment in Philippines



HUAWEI

Huawei Philippe Support： 7X24 hotline，Spare parts 2BD ship out after RMA

APAC & Philippines Support Team



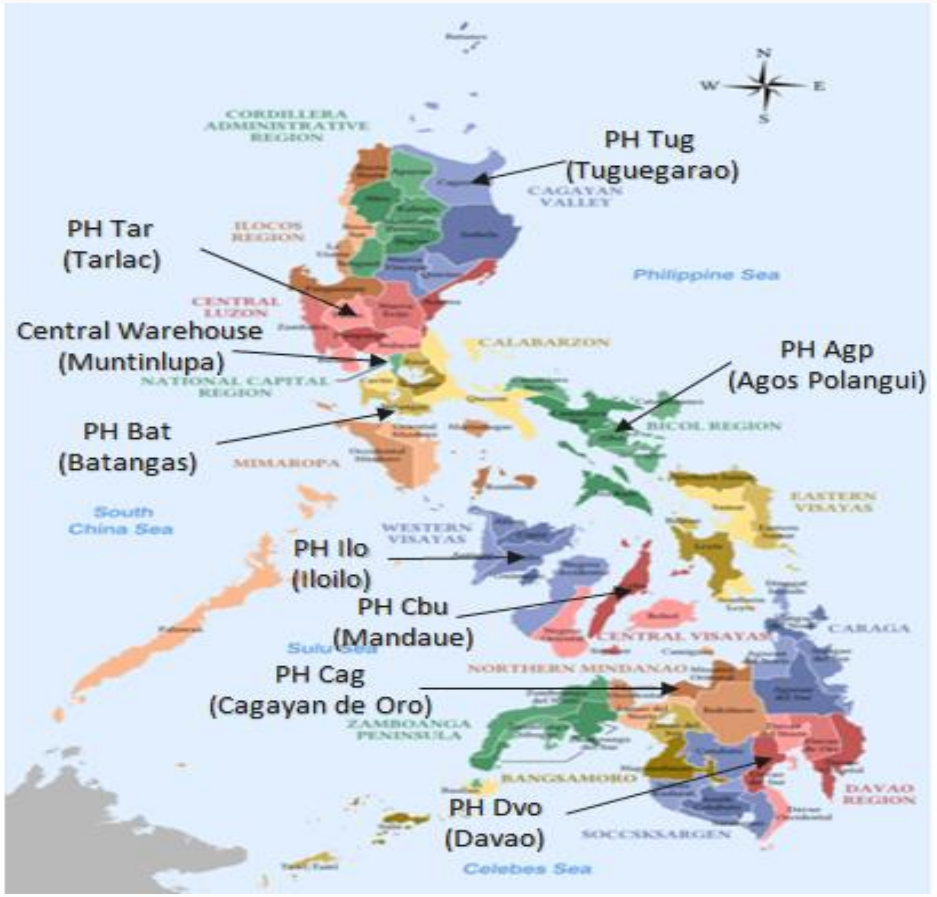
Huawei Hotline Certified By:

Philippine Hotline:
1800-1888-6868
For More Global Service Hotline refer to the link:
http://e.huawei.com/en/service-hotline

Email of APAC Technical Service Center :
APSupport@huawei.com

Our specialist will feedback on phone or email within 30 minutes.

Philippine Spare Warehouse Network



1 main spare center in Muntinlupa and **8 regional spare warehouses** covering whole country for support

HUAWEI

World's largest hydro-solar plant

Sichuan Yalong River Hydro-solar hybrid project

(Utilizing same ±800kV UHVDC transmission line, adjust hydro plant for PV to achieve complementary output)

Total plant capacity **1 GW PV + 3GW Hydro**

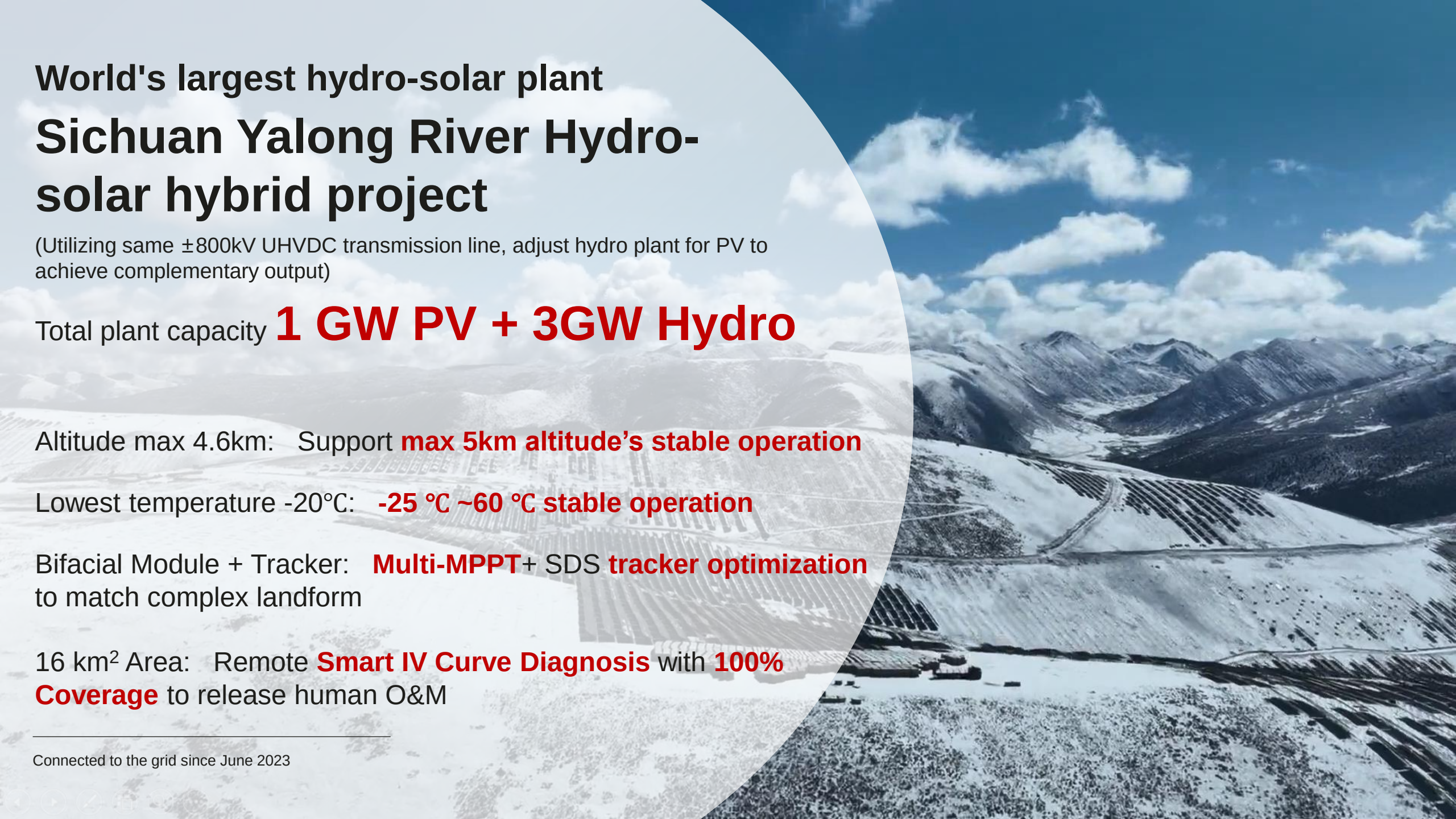
Altitude max 4.6km: Support **max 5km altitude's stable operation**

Lowest temperature -20℃: **-25 ℃ ~60 ℃ stable operation**

Bifacial Module + Tracker: **Multi-MPPT**+ SDS **tracker optimization** to match complex landform

16 km^2 Area: Remote **Smart IV Curve Diagnosis** with **100% Coverage** to release human O&M

Connected to the grid since June 2023



Datang Yuhu Floating PV Plant in Fuzhou, China

World's first plant using the Smart Co-Diagnosis System

The largest solar-fishery plant in Jiangxi in 2021

The total capacity of the plant is **260 MW**, among which **34 MW** is deployed with the co-diagnosis system in the first phase.

After the co-diagnosis system identifies faults and guides troubleshooting, the energy yield increases by **1%–2%**.

It is estimated that the annual revenue of the 34 MW project will increase by about **CNY236,000**.*

Within 5 months after the system is deployed, the average O&M efficiency is improved by **about 80%**.

**The energy yield increases by 1.5%. The plant has a total of 1112.9 equivalent sun hours annually, and the electricity price is CNY0.4143/kWh.*

ACEN San Marcelino 384 MWp Project

Currently the Philippines' largest PV plant

Passed VRE Test in 2 days

PAVI Bataan 20 MW Project

Commissioned late 2023

Implements a skid solution

NV Vogt SE4 8.84 MWp

Located in Armenia, Tarlac

0.5% failure rate from 2016 onwards

Cabanatuan 10 MW Project

Located in Nueva Ecija

0.2% failure rate after 5 years

Saudi Arabia Red Sea Project

World’s Largest 100% PV + ESS Microgrid Project

400 MW / 1.3 GWh

Serving 100% PV + ESS power supply for **1 million people** in Red Sea new city

Grid Forming enabling 100% PV & ESS grid

COD: Oct. 2023

Sembcorp BESS Project, Singapore

(Spinning Reserve, Frequency Regulation)

Largest BESS Project in Southeast Asia

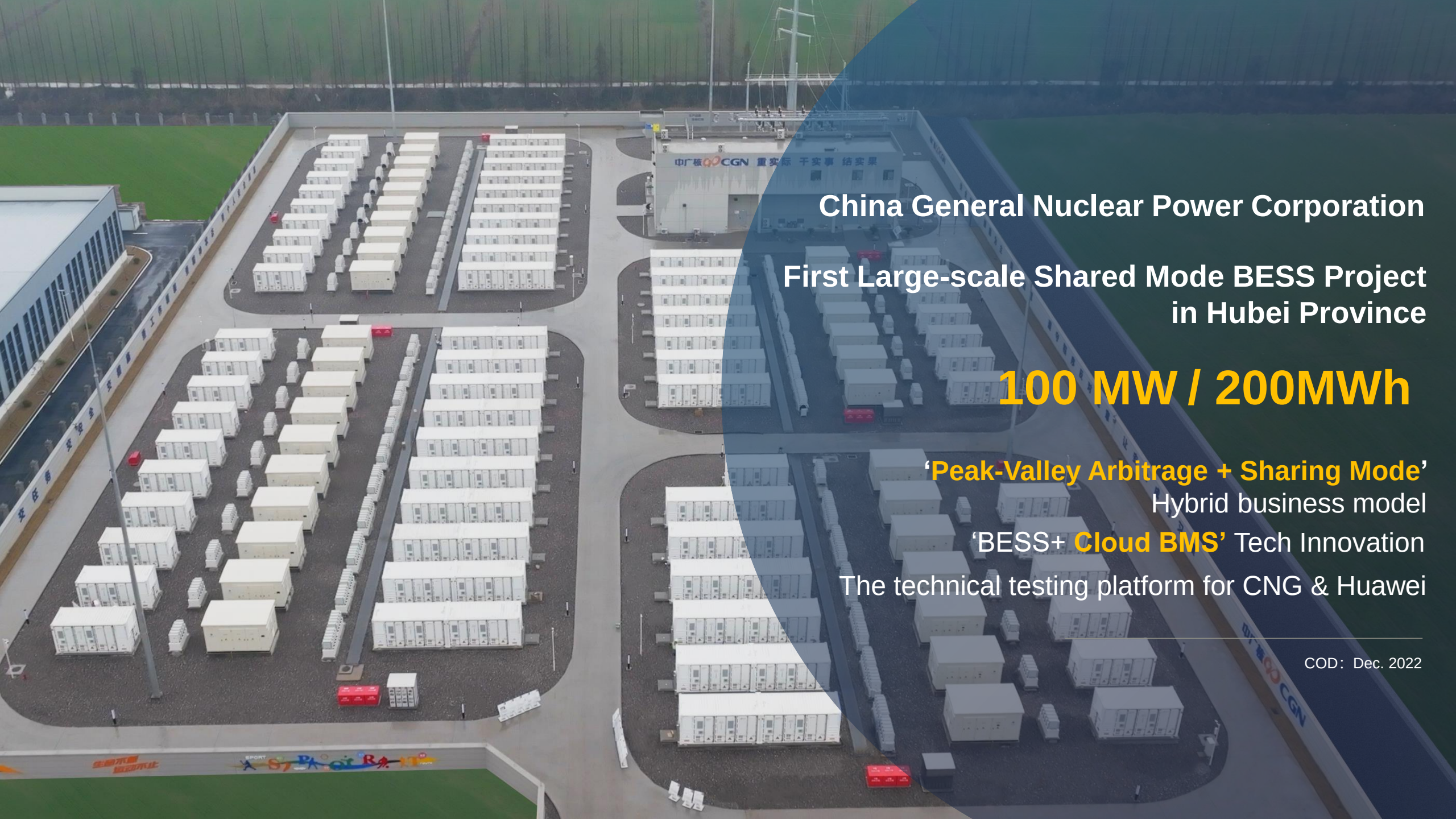
115MW / 146MWh

Longer consistent power thru Rack-level Optimization
Realizing more revenue of grid auxiliary service

Automatic SOC calibration, save O&M cost

Safe & reliable, comply with the strict local safety standard
Conform to EN ISO 1182 and EN ISO 1716
Acquired CoC certificate

COD: Nov. 2022



China General Nuclear Power Corporation

First Large-scale Shared Mode BESS Project in Hubei Province

100 MW / 200MWh

‘Peak-Valley Arbitrage + Sharing Mode’
Hybrid business model

‘BESS+ **Cloud BMS’** Tech Innovation

The technical testing platform for CNG & Huawei

COD：Dec. 2022

PV plant in Gonghe, Qinghai

World's first
successful test of the smart grid-forming solution

Quick active power adjustment response –
Startup time < 5 ms

Transient voltage control speed –
Reactive power response < 10 ms

Short-circuit capacity –
Three-fold overcurrent protection capability

In 2022, Huawei teamed up with the China Electric Power Research Institute, State Grid Qinghai Electric Power Company, and CR Power to test and verify the smart grid-forming solution in the world's first grid-connection performance test.

Thank you.

把数字世界带入每个人、每个家庭、
每个组织，构建万物互联的智能世界。

Bring digital to every person, home and organization for a fully connected, intelligent world.

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